GRAND RIVER BASIN WATER MANAGEMENT STUDY

TECHNICAL REPORT SERIES

REPORT #28

URBAN NON-POINT SOURCE POLLUTION AND CONTROL

Prepared for the Grand River Implementation Committee

by

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FOREWORD

The report "Urban Non-Point Source Pollution and Control" is one of a series of technical documents prepared for the Grand River Basin Water Management Study. The project described herein was undertaken through the Grand River Study Team at the request of the Grand River Implementation Committee.

The material contained in these reports is primarily technical support information and, in itself, does not necessarily constitute policy or management priorities. Interpretation and evaluation of the data and findings, in most cases, cannot be based solely on this one report but should be analyzed in light of other reports produced within the comprehensive framework of the overall study. Questions with respect to the contents of this report should be directed to the Co-ordinator of the Grand River Study, Water Resources Branch, Ministry of the Environment, 135 St. Clair Avenue West, Toronto.

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1. INTRODUCTION

The general goals of the Grand River Basin Water Management Study are:

1. to develop viable water management options needed to plan for, and encourage, the integrated use of water and land resources, within the Grand River Basin;

2. to identify the necessary trade-offs to achieve protection against flooding, acceptable disposal and transport of waste effluents;

3. to provide adequate supplies of good quality water to meet water supply, aesthetic, fish, wildlife and recreation desires and needs; and

4. to ensure a productive and fulfilling environment for the people of the basin.

In summary, the three water management objectives of the Grand River Basin Study are to reduce flood damages, to provide adequate water supply and to maintain an acceptable water quality.

Water quality constitutes an important component of the Grand River Basin Water Managemetn Study. The key elements of the water quality component of the basin study are:

1. to determine existing water quality conditions and relate them to various water uses;

2. to identify the type, magnitude, relative significance and impact of pollutants from point and non-point (urban and rural) sources on the water quality of the river; and

3. to develop water quality management programs to preserve areas of high water quality and to upgrade areas where poorer water quality exists.

Urban stormwater runoff has been recognized as a potential major contributor of pollutants to the Grand River. Therefore, investigation of pollution from urban sources became an integral part of the basin's water quality assessment program, and this study was initiated to assess the impact of urban stormwater runoff on the river and to determine its significance in relation to sewage treatment plant discharges and rural non-point sources.

The objectives of the urban non-point source study are:

1. to assess present urban non-point source pollutant loads from the major population centres in the Grand River basin;

2. to estimate future loadings based on projections of populations (low, medium and high) for the years 2001 and 2031; and

3. to evaluate the present and future impact of pollutant loadings on water quality and uses in the Grand River and to identify remedial measures, if any, for implementation.

This report is divided into seven sections. A general description of the Grand River basin and information on land use, population, major urban centres and water quality are given in Section 2. Section 3 describes urban land use and runoff data collected under the Canada-Ontario Agreement on Great Lakes Water Quality Program, the Pollution from Land Use Activities Reference Group (PLUARG) Program, and the Grand River Basin Water Management Study Program. The characteristics of urban runoff in the Grand River basin are described in Section 4. In Section 5, the simulation of urban runoff quantity and quality, including the calibration and verification of the Storage, Treatment, Overflow, Runoff Model (STORM), are described. The impact of urban stormwater runoff on the Grand River are discussed in Section 6 and conclusions and recommendations are given in Section 7.

2. DESCRIPTION OF THE GRAND RIVER BASIN

2.1 GENERAL

The Grand River basin is located in southwestern Ontario between longitudes 79° 30' and 80° 57'W, and latitudes 42° 51' and

44^{o} 13' N. The basin occupies the central part of a peninsula bounded on the north by Georgian Bay, on the west by Lake Huron, on the south by Lake Erie and on the east by Lake Ontario (Figure 1). The basin has an area of 6965 km^2, a length of about 300 km and a width which varies between 5 and 75 km.

The headwaters of the Grand River rise in a massive swampy upland south of Georgian Bay at an elevation of approximately 525 m above mean sea level (msl). The river flows in a southerly direction until it reaches the Town of Paris. From there it follows a southeasterly direction to discharge into Lake Erie at Port Maitland at an elevation of 174 m above msl. The Conestogo, Speed and Nith rivers are the three major tributaries which join the main stem in the middle portion of the basin. The Conestogo River drains the northwestern portion of the basin with the Speed and Nith rivers draining the eastern and western portions of the basin, respectively. In the upper part of the basin, the Grand and its tributaries flow in previously formed glacial spillway channels. In the lower part, below the City of Brantford, the river has scoured its own channel across glacial lake deposits of silt and clay.

The drainage basin is characterized by a temperate climate that receives a moderating influence from the nearby Great Lakes System. The long-term mean annual temperatures vary from $6^{o}C$ in the headwaters to $9^{o}C$ at Lake Erie. The long-term mean annual precipitation varies from 84 cm (178 cm snow) in the lower reaches to 88 cm (127 cm snow) in the upper reaches of the basin.

The mean annual flow at the outlet of the river is estimated to be 64 m^3/s which corresponds to a mean annual runoff of 30 cm of precipitation. Peak flows range from 500 to 1400 m^3/s. In general, peak flows occur during the spring melt period. The highest flow on record, occurred in May, 1974 when a flow of 1784 m^3/s was recorded at the Brantford streamflow gauging station.

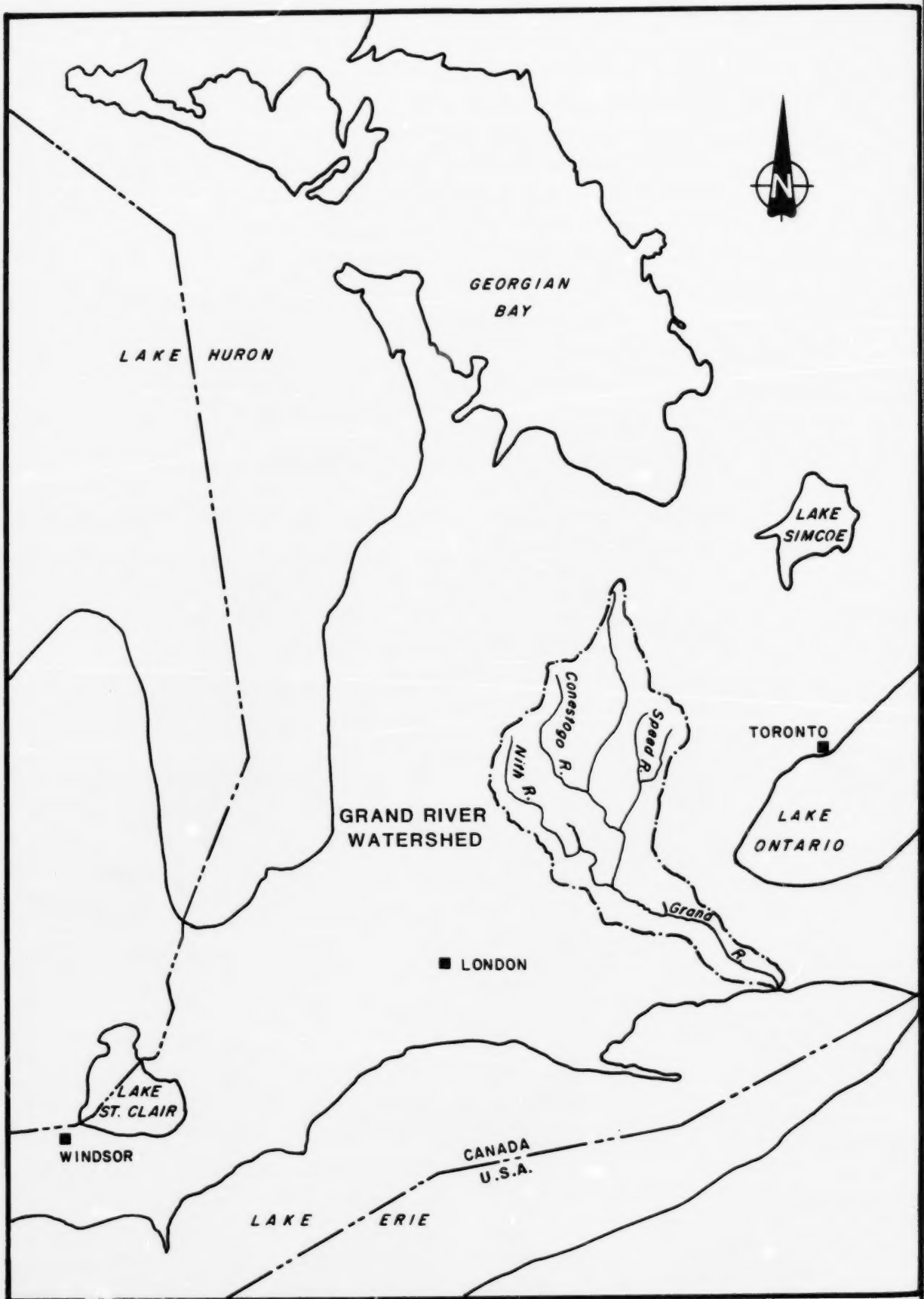

Figure 1 : Location of the Grand River Basin in Southwestern Ontario

2.2 LAND USE, POPULATION AND MAJOR URBAN CENTRES

The Grand River basin has been developed extensively for urban and agricultural uses which comprise 3% and 77% of the total basin area, respectively. Wooded and/or idle areas account for approximately 19% of the basin area and the remaining 1% lies in other uses. Urban uses are predominant in the central portion of the basin where the cities of Kitchener, Waterloo, Guelph, Cambridge and Brantford are located (Figure 2).

The population of the basin in 1976 was approximately 573,000 and was primarily concentrated in the above mentioned five large urban centres. This, however, has not always been the case. In 1921, 43% of the basin's population was rural and only 47.5% lived in the five urban centres (Table 1). By 1976, however, the proportion of rural population dropped to about 20% whereas the proportion of population in the five urban centres increased to 72%. If these trends continue through subsequent years, it can be expected that the urban population by the year 2001 might increase by about 200,000 to 300,000 people. This could increase pollution loadings to streams from urban runoff, further impair water quality conditions and tax available water supplies.

The land use distribution and drainage systems in the five major cities in the basin are described in the following sections.

Brantford

The City of Brantford is located on the Grand River approximately 91 km north of Lake Erie (Figure 3). It has a developed area of 3214 ha with a land use distribution of: residential 52.6%, commercial 4.9%, institutional 4.5%, industrial 16.0% and open space* 21.7%.

Brantford is the centre of agricultural machinery manufacturing in Canada. Industries in the city produce a wide range of goods including chemicals, building products, pulp products, refrigeration units, construction machinery, school buses and transport trailers.

Table 1. Population in the Grand River

	1921	1941	1966	1976	Population Projections for 2001*** Low	Medium	High	Population Projections for 2031*** Low	Medium	High
Cities										
Brantford	29440	31948	58395	66930	85833	94982	105063	115690	144565	180485
Cambridge	21416	25108	51482	71482	116815	124474	129525	128524	178662	205495
Guelph	18128	23273	49497	70374	97000	122206	137219	128393	215883	280419
Kitchener	21763	35657	91376	131801	210795	224486	233514	231724	321340	369301
Waterloo	5883	9025	29770	49972	96461	102131	105869	105128	142237	162098
Total population	96630	125011	280520	390599	606904	668279	711190	709459	1002687	1197798
% of basin population	47.5	53.0	68.2	71.3	76.2	75.6	74.3	76.9	76.1	74.1
Avg. annual growth rate %	1.3	3.3	3.4	1.8*	2.2*	2.4*	1.1**	1.7**	2.1**	
Towns and Villages										
Total population	18589	20818	35961	43541	58896	69114	79387	79571	110911	141827
% of basin population	9.1	8.8	8.7	8.0	7.4	7.8	8.3	8.5	8.4	8.8
Avg. annual growth rate %	0.6	2.2	2.1	1.2*	1.9*	2.4*	1.1**	1.7**	2.2**	
Rural Areas										
Total population	88204	89795	95118	113646	130948	147114	166290	146246	204243	276054
% of basin population	43.4	38.0	23.1	20.7	16.4	16.6	17.4	15.6	15.5	17.1
Avg. annual growth rate %	0.09	0.23	1.5	0.6*	1.0*	1.5*	0.5**	1.1**	1.6**	
Total basin population	203423	235624	411599	547786	796748	884507	956867	935276	1317841	1615679
Avg. annual growth rate %	0.74	2.3	2.8	1.5*	1.9*	2.3*	1.0**	1.6**	2.0**	

* Annual growth rate between 1976 and 2001
** Annual growth rate between 1976 and 2031
*** Grand River Implementation Committee, 1980

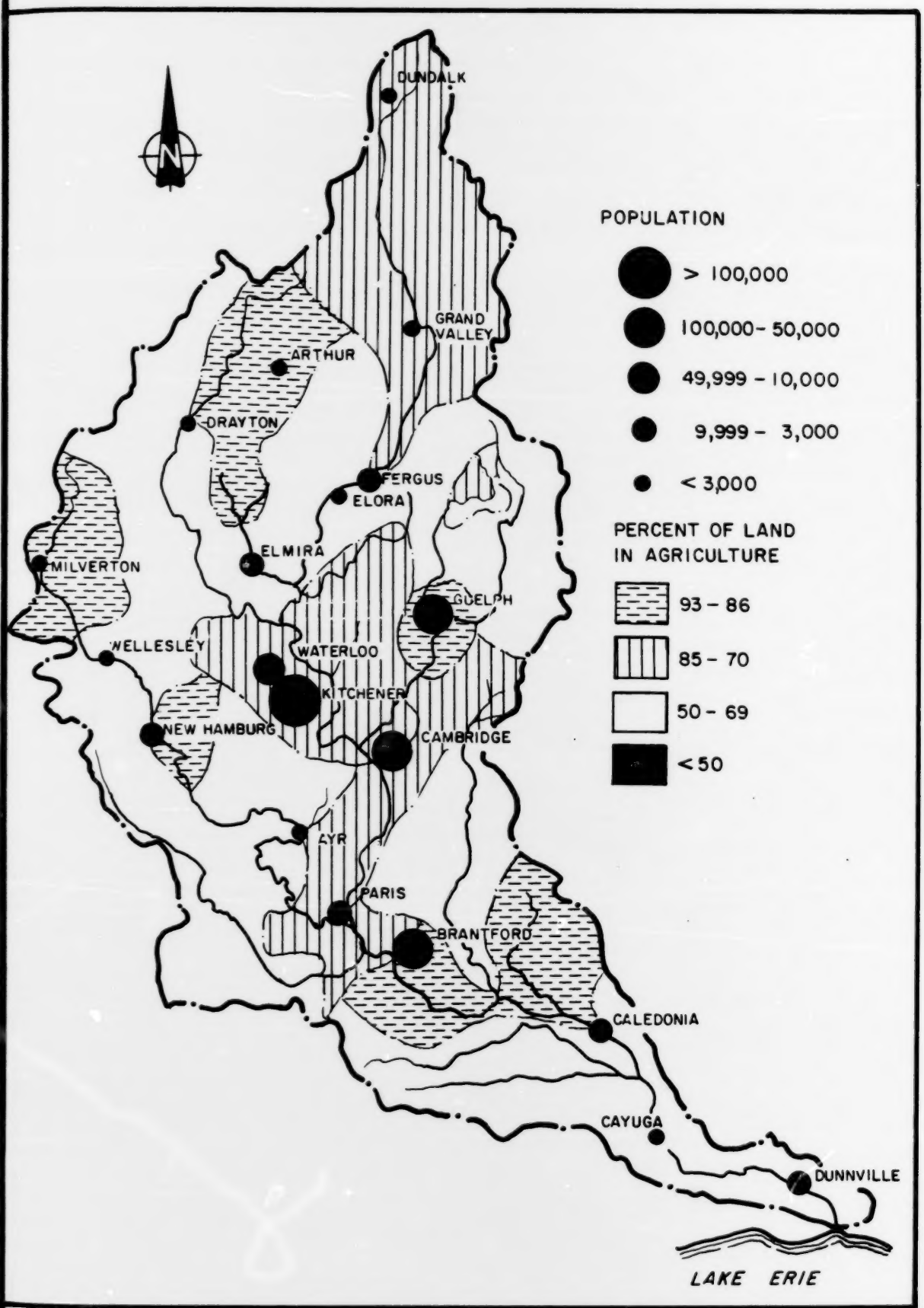

Figure 2 : Population and Land Use Distribution in the Grand River Basin

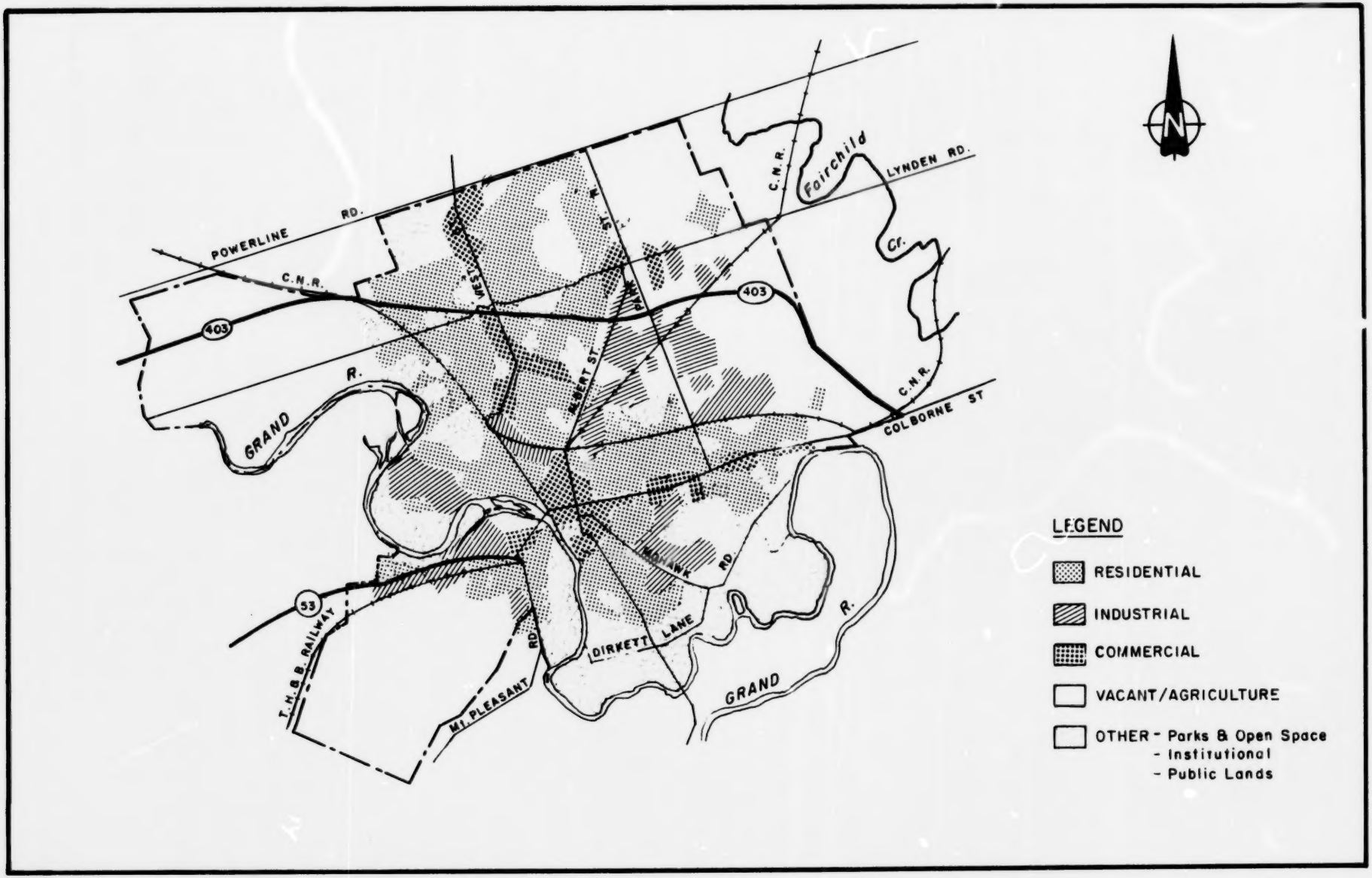

Figure 3 : Existing Land Use (1979) in the City of Brantford

Approximately 30% of the City area is drained via an essentially separate storm sewer system to the Grand River, 35% to Fairchild's Creek, 30% to Mohawk Creek, 3% to Paper Mill Creek and 2% to D'Aubigny Creek. In 1978, the City conducted a survey of the storm sewer system and detected the presence of domestic sewage in some of the storm sewers underlying the old section of the City. In addition, inflows to the Brantford Water Pollution Control Plant increased during storm events because of infiltration.

Cambridge

Cambridge is located at the confluence of the Speed River and Grand River (Figure 4). The City has a total developed area of 3675 ha. The land uses are: residential 52.5%, commercial 10.3%, institutional 4.5%, industrial 14.0% and open space 18.7%.

The Cambridge area has been a centre of shoes, textiles and metal-working industries. Recently, a second group consisting of manufacturers of chemical products and electronic components was established in the area.

Each of the three main community areas (Hespleler, Preston and Galt) has its own separate storm sewer system. The storm sewer system in Hespeler discharges to the Speed River whereas in Preston it discharges to both the Speed River (50%) and the Grand River (50%). Approximately 30% of storm runoff from Galt discharges to Galt Creek and the remaining 70% to the Grand River. Occasional surcharge of several old storm sewers was the only problem noted in the three storm sewer systems.

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* Parks, cemeteries,... etc.

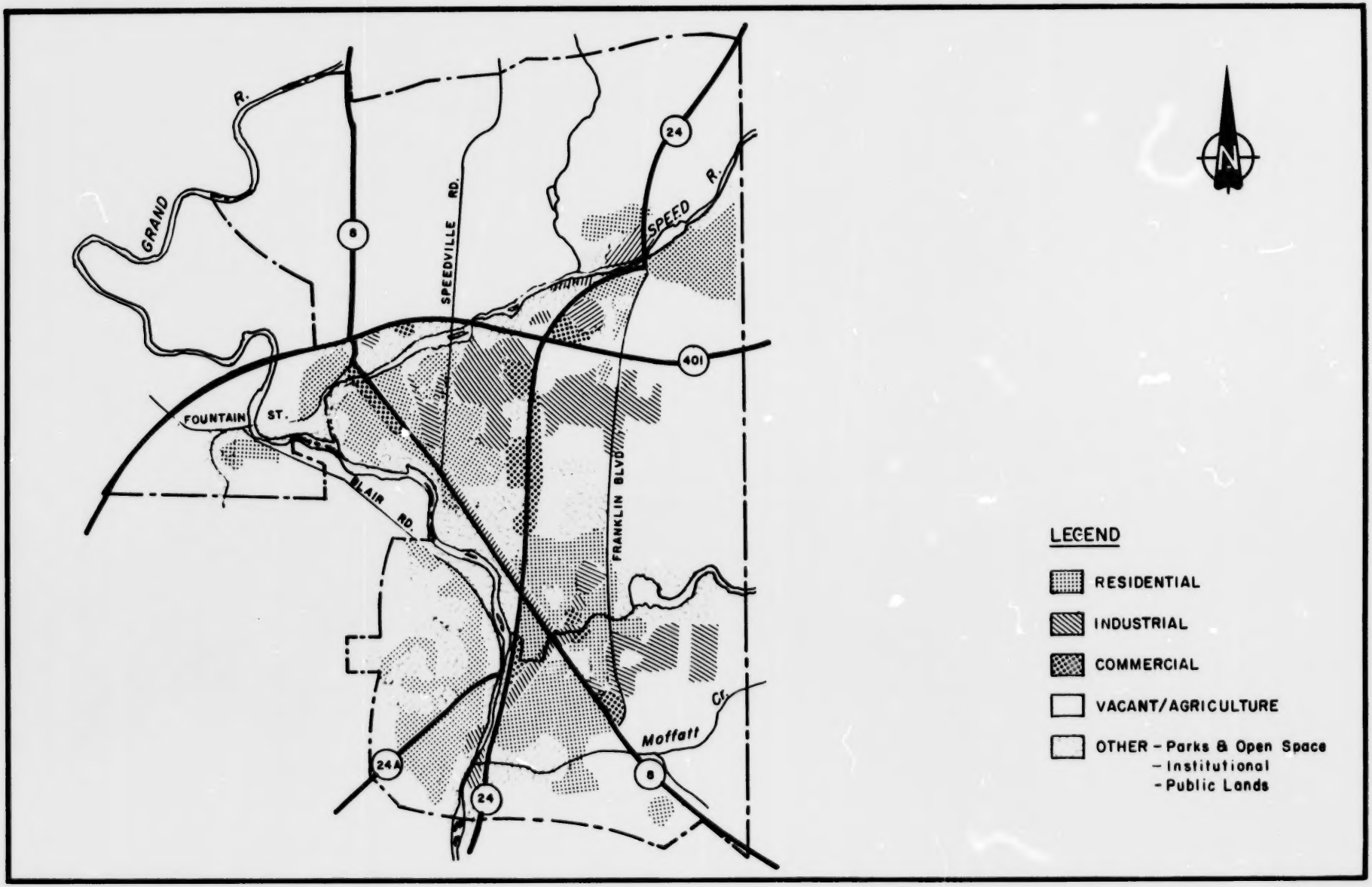

Figure 4 : Existing Land Use (1979) in the City of Cambridge

Guelph

Guelph is located at the confluence of the Speed River and Eramosa River (Figure 5). The city has a developed area of 3080 ha which incorporates the following land uses: residential 50.5%, commercial 3.5%, institutional 12.8%, industrial 13.6% and open space 19.6%.

The Guelph industrial base is notable for its diversification. The industries in the city produce a wide range of products which include hydro-electric transformers, electrical and radio supplies, steel fabricating and building products, freezers, chemicals, food products and cigarettes.

The City has completely separate sanitary and storm sewer systems. The storm sewer system discharges into the Speed River (70%) and Eramosa River (30%).

Modern stormwater management concepts are being implemented in some of the developing subdivisions in the city. Ponds are used in three new residential subdivisions for sedimentation and ground water recharge; another pond is under construction in a developing industrial zone.

Kitchener - Waterloo

The twin cities of Kitchener and Waterloo are located in the central part of the Grand River Basin (Figures 6 and 7). The cities have a combined developed area of 7864 ha which have the following land uses: residential 39.7%, commercial 5.9%, institutional 2.9%, industrial 14.7% and open space 36.8%. In comparison with the other three cities, the Kitchener-Waterloo urban area has the largest and most advanced industrial base. Major industries include furniture, automotive components, tire and shoe manufacturing, meat packing, brewers and distillers.

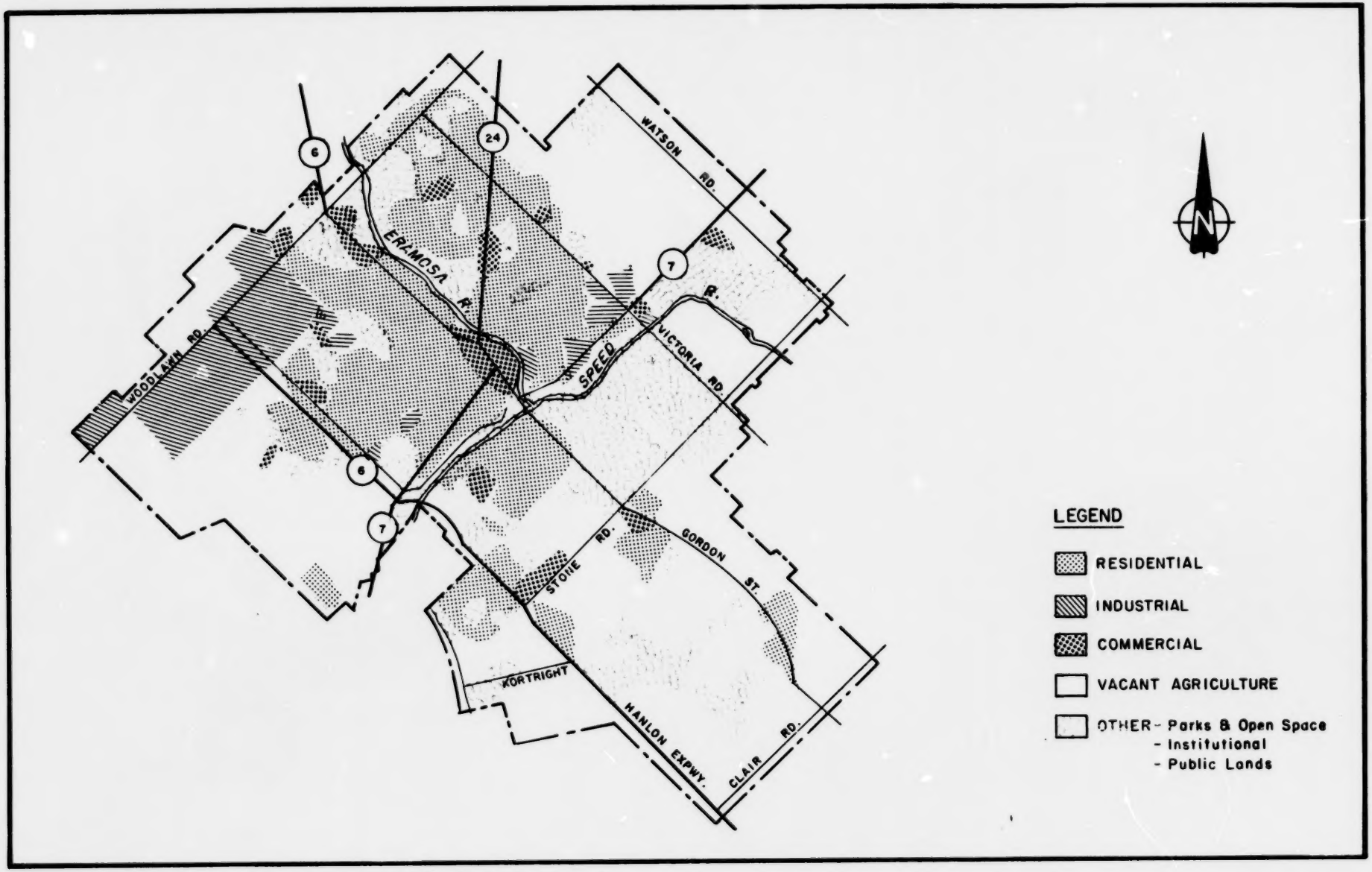

Figure 5 : Existing Land Use (1979) in the City of Guelph

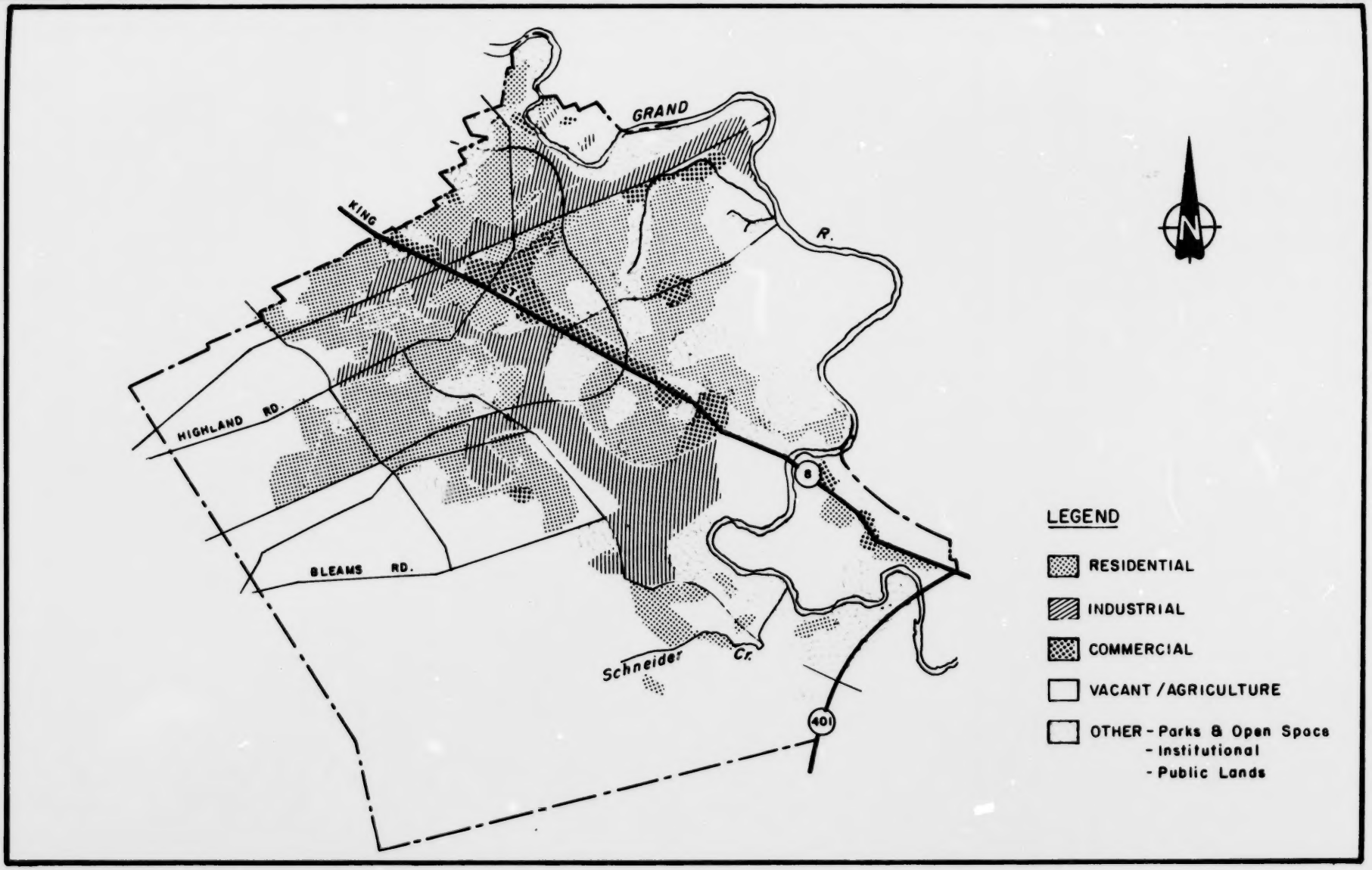

Figure 6 : Existing Land Use (1979) in the City of Kitchener

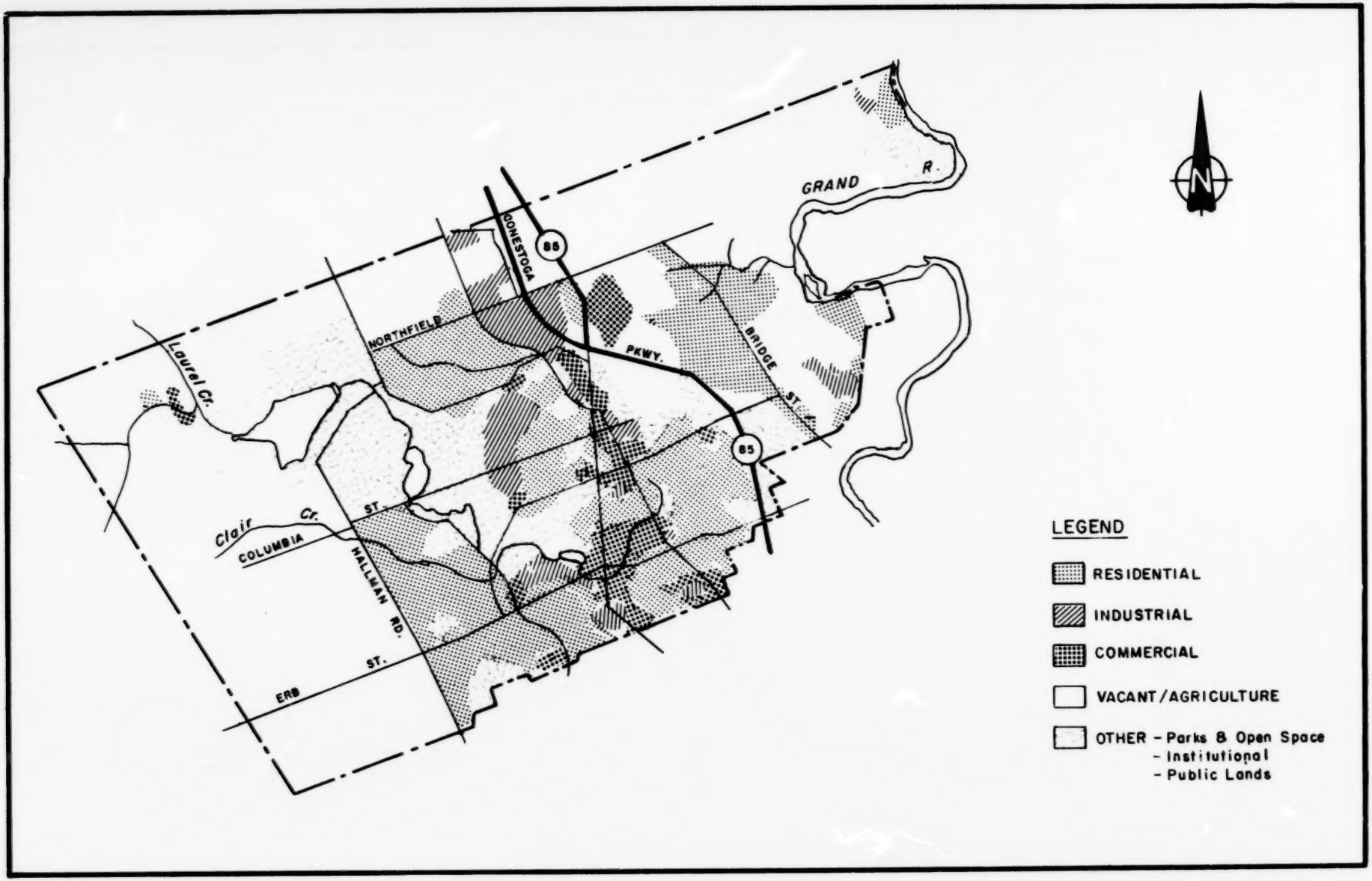

Figure 7 : Existing Land Use (1979) in the City of Waterloo

The City of Waterloo is served by separate sanitary and storm sewer systems. The storm sewer system discharges at several locations along Laurel Creek and its tributaries. The City of Kitchener has essentially separate sanitary and storm sewer systems except in the old section of the City where house foundation drains are connected to the sanitary sewers because the storm sewers are placed at inadequate depths. Schneider Creek and its tributary Montgomery Creek receive about 80% of Kitchener's stormwater runoff while the remaining 20% drains directly to the Grand River.

In 1979, the City of Kitchener (Dillon, 1979) adopted an urban drainage policy to ensure orderly urban growth. The new policy requires that:

1. storm drainage systems shall be designed using the major-minor concept*;

2. new subdivisions shall consider the effects of the proposed development on the existing drainage regime and if necessary, carry out mitigative measures, as required;

3. subdivision proposals shall include erosion and sediment control measures; and
4. the municipality shall develop a Master Drainage Plan for the City of Kitchener.

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*The essence of the major-minor drainage concept is to extend protection of basements and buildings to the 1:100 year or Regional Storm levels, while still provide convenience at the 1:5 year level. The minor drainage system comprises swales, street gutters, catch basins and storm sewers. The major drainage system comprises the natural streams and valleys, streets, man-made swales, channels and ponds.

2.3 WATER QUALITY

At present, water quality in the northern part of the Grand River basin, upstream of the Town of Fergus where agricultural land use predominates, is affected primarily by erosion. Soils, nutrients, bacteria and pesticides are carried into the river causing turbidity, nutrient enrichment, localized algae growth and high levels of bacteria. During 1975 and 1976, the upper part of the basin contributed on the average about 4200 tonnes of suspended solids (51.3 kg/ha/year), 17 tonnes of total phosphorus (0.2 kg/ha/year) and 229 tonnes of total Kjeldahl nitrogen (2.7 kg/ha/year). At the first concession downstream of Belwood Lake, the annual mean concentrations of suspended solids, total phosphorus and total Kjeldahl nitrogen were 18 mg/L, 0.06 mg/L and 0.75 mg/L, respectively. With the exception of localized aquatic growth, water quality problems in this part of the basin are limited in extent.

The heavily urbanized and industrialized central part of the basin is significantly affected by the discharge of treated domestic and industrial wastes, urban stormwater runoff as well as agricultural runoff. Two of the major problems that have been identified through the Grand River Study are: 1) the reduction of dissolved oxygen in areas downstream from the major municipalites caused by municipal discharges of oxygen-consuming wastes; and 2) profuse algae and plant growth stimulated by nutrient inputs from point and non-point sources. This growth chokes the river causing aesthetic impairment. In addition, the nocturnal respiration of the plant life reduces dissolved oxygen in the river to levels below Provincial Water Quality Objectives* (MOE, 1978).

The western part of the basin includes the Conestogo River, the Nith River, Canagagigue Creek and Irvine Creek watersheds. At present, these watersheds are used extensively for agricultural production and contribute significant amounts of pollutants to receiving waters. For example, during 1975 and 1976, the pollutant loads measured at the mouth of the Nith River averaged 70208 tonnes of suspended solids (688 kg/ha/year), 124 tonnes of total phosphorus (1.2 kg/ha/year) and 532 tonnes of total Kjeldahl nitrogen (5.2 kg/ha/year). These loads are much higher than those measured at the northern part of the Grand River basin reflecting more intensive agricultural activities.

The lands of the lower part of the basin are primarily used for agriculture and the problems encountered there are quite similar to those identified earlier for the northern part of the basin (Jeffs et al, 1979). Present pollutant loads from the lower Grand River basin are relatively low (So and Singer, 1982). For example, during 1975 and 1976, the lower part of the basin contributed 75 tonnes of total phosphorus (0.6 kg/ha/year) and 222 tonnes of filtered nitrite and nitrate (1.8 kg/ha/year).

3. DATA COLLECTION PROGRAMS

3.1 MOE - COA PROGRAM

A data collection program on urban runoff in the Grand River basin was initiated by the Ontario Ministry of the Environment (MOE) and supported by the Canada-Ontario Agreement on Great Lakes Water Quality (COA) for a duration of two years (1975-1976). Under this program, two urban catchments (the North and West catchments) were established in the City of Guelph and instrumented for quantity (precipitation and runoff) and quality monitoring.

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*The Ministry of the Environment suggests that for the protection of warm-water biota, which occupy most reaches of the Grand River, dissolved oxygen levels should not fall below 47% saturation (i.e. 4 mg/l at $20^{o}C$).

The objectives of the program were to investigate the variation of quantity and quality of stormwater runoff; to document the difficulties encountered in the selection and instrumentation of representative urban catchments; and to investigate the applicability of the Storage, Treatment, Overflow, Runoff Model (STORM) for prediction of urban runoff quantity and quality.

The North Catchment is located at the northern limits of the City of Guelph (Figure 8). The catchment is a relatively new suburban development consisting primarily of single family residential land use (82.9%) with minor areas of multiple family residential (3.5%), commercial and institutional (6.2%) and open space (3.3%). The area of the catchment is 58.8 ha with a total imperviousness of 39.0%.

The West Catchment (Figure 8) is adjacent to the downtown core of the City of Guelph. The catchment (234.8 ha) represents a range of old and recently developed land uses, consisting of single and multiple family residential (44.9%), commercial (3.1%), industrial (29.5%) and open space (22.5%). The total imperviousness of the catchment was estimated at 32.3% (Novak, in press).

Precipitation in both catchments was measured using two Leopold and Stevens tipping bucket rain gauges of capacity of 0.254 mm. Flow measurements were made at the outlets of both catchments. Samples were collected manually during the first phase of the program and using a manually activated automatic sampler during the second phase of the program. These samples were analyzed for the following parameters:

five-day biochemical oxygen demand,
chemical oxygen demand,
solids (total and suspended),
phosphorus (total and filtered reactive),
nitrogen (free ammonia, Kjeldahl, nitrite and nitrate),
iron, lead and chloride,
coliforms (total and fecal) and streptococcus sp.,
conductivity, and phenols.

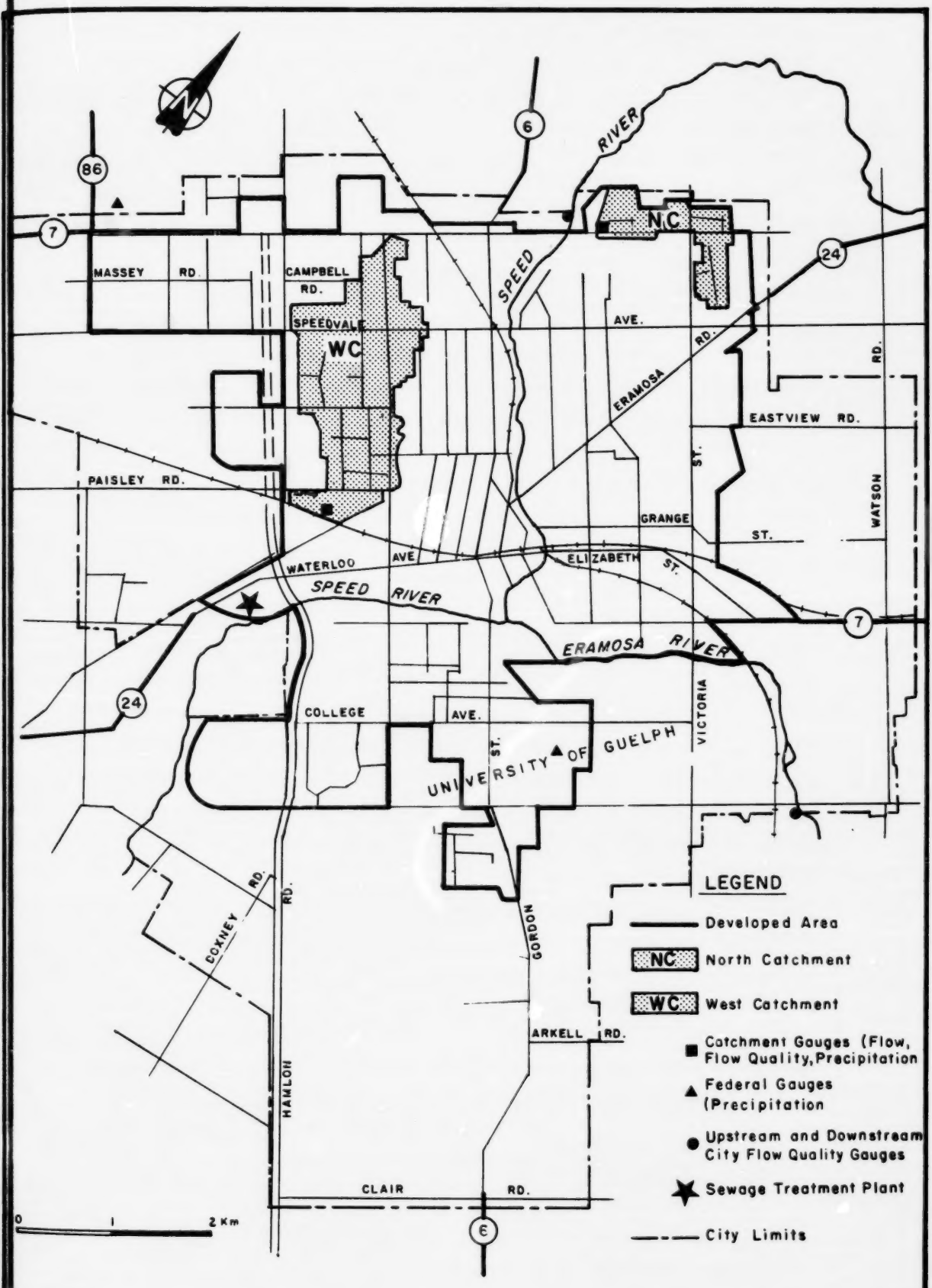

Figure 8 : Location of the Northern and Western Urban Catchments and Quantity and Quality Monitoring Stations in the City of Guelph (After Novak, 1979)

During this program a total of 14 events were monitored in the North Catchment and 13 events in the West Catchment. Unfortunately, only four events in the North Catchment and two in the West Catchment were completely monitored in terms of precipitation, flow and quality. This program clearly indicated that automatic sampling stations are essential for the successful collection of urban runoff quality data.

3.2 PLUARG PROGRAM

Another data collection program on urban runoff was established in the Grand River basin under the Pollution from Land Use Activities Reference Group (PLUARG) during the period 1975-1977. The objectives of that program were to determine the sources of pollutants within urban areas, estimate their magnitude in terms of unit-area loadings, determine their relative significance and investigate the nature of their transport from urban areas.

Three urban areas were selected in the Grand River basin for the study, namely: the megalopolis of Kitchener-Waterloo-Cambridge, the City of Guelph and the Town of New Hamburg. In addition, two small urban watersheds were monitored, namely: Schneider Creek and Montgomery Creek. Monitoring stations were established upstream and downstream of the urban areas for the purpose of collecting flow and quality information for pollutant loading estimates (Figure 9). The difference between the pollutant load measured at the outlet (downstream) station, and the inflow (upstream) stations was considered to be the net pollutant load from the study area. The load from the urban sources was then estimated by subtracting measured point sources and other non-urban diffuse sources from the net pollutant load (O'Neill, 1979).

Stream Water and suspended sediment samples collected at each monitoring station were analyzed for the following parameters:

Water Sample	Sediment Sample
Total Phosphorus	Total Phosphorus
Filtered Reactive Phosphorus	Total Nitrogen
Filtered Nitrogen (Nitrate & Nitrite)	Copper

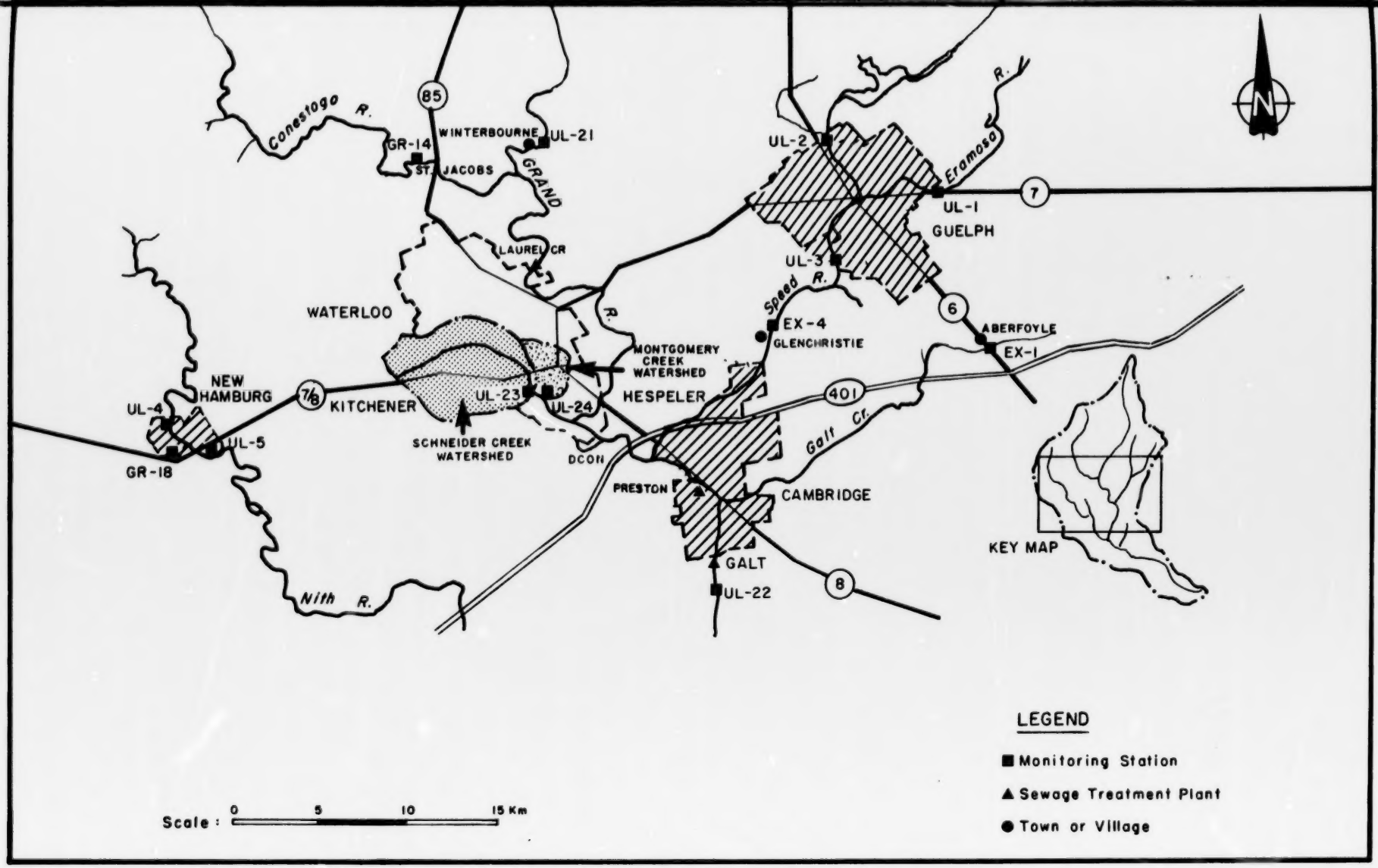

Figure 9 : Urban Areas in the Grand River Basin Monitored Under the PLUARG Program

Total Kjeldahl Nitrogen	Chromium
Suspended Sediment	Cobalt
Lead	Lead
Copper	Zinc
Zinc	Mercury
Chloride	Arsenic
Bacteria	Nickel
	Organochlorine Pesticides
	PCBs

Emphasis was placed on the above parameters because they were thought to contribute to eutrophication or toxicity problems in the Great Lakes.

3.3 GRAND RIVER BASIN WATER MANAGEMENT STUDY PROGRAM

During the Grand River Basin Water Management Study, monitoring of the quantity and quality of urban runoff from the City of Kitchener continued in the Schneider Creek and Montgomery Creek watersheds.

Schneider Creek (Figure 10) drains the western portion of the City of Kitchener. The drainage area is 3577 ha and consists of 60% urban, 35% agricultural and 5% wooded land. The major land uses in the urban area are: residential (primarily single family dwellings) 42%, commercial 5%, industrial 4%, recreational 8%, and transportation 1%. The watershed has an estimated population of 74,000 and is serviced by separate storm and sanitary sewer systems. The storm sewer system discharges at several locations along Schneider Creek.

Montgomery Creek (Figure 10) drains the eastern portion of the City of Kitchener. The watershed has an area of 958 ha which consists of 96% urban and 4% wooded land. The major land uses in the urban area are: residential 64%, recreational 13%, commercial 12%, transportation 6% and industrial 1%. The watershed has a population of 58,000 and is serviced by separate storm and sanitary sewer systems. The storm sewer system empties into Montgomery Creek at several locations.

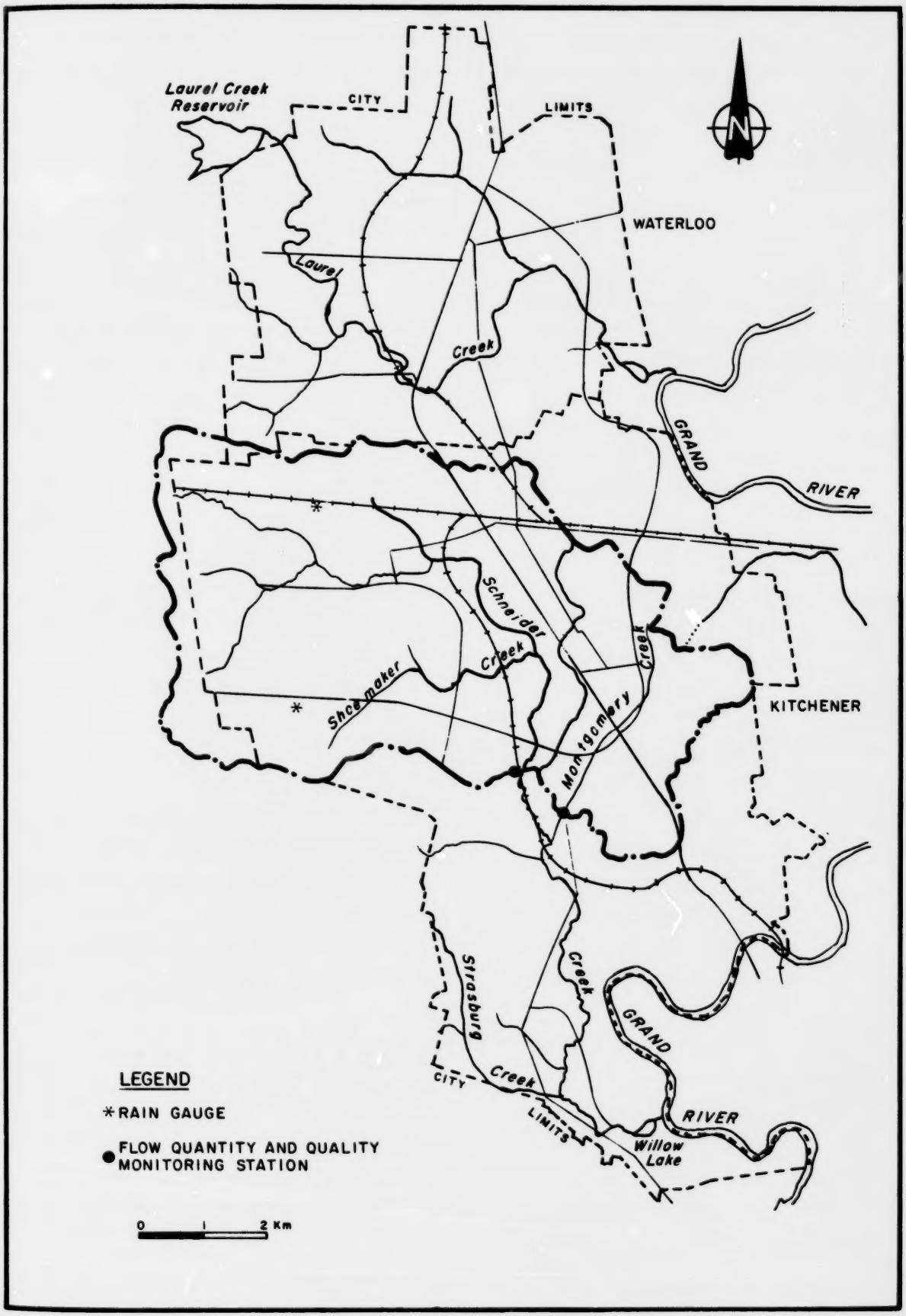

Figure 10 : Schneider Creek and Montgomery Creek Watersheds

Precipitation was measured at two locations in the Schneider Creek watershed and at one location in the Montgomery Creek watershed, using three tipping bucket rain gauges. Flow data were obtained at the outlets of both watersheds and stream water samples were collected using two automatic samplers. Details of flow measurements, sample collection techniques, handling and analytical procedures are discussed in a methodology report produced by MOE (Onn, 1980).

During the monitoring period, a total of 22 hydrographs and 10 pollutographs were obtained for Schneider Creek, and 14 hydrographs and 4 pollutographs for Montgomery Creek. The pollutographs, based on a sampling frequency ranging from 15 to 30 minutes, were produced for suspended solids, five-day biochemical oxygen demand, total phosphorus, filtered reactive phosphorus, total Kjeldahl nitrogen, filtered ammonia, chloride and lead.

In addition, at the time of initiation of the Grand River Basin Water Management Study in 1975, a network of seven continuous monitoring stations was established to monitor important water quality parameters in the central megalopolis area of the basin (Figure 11). Dissolved oxygen and temperature were monitored continuously at five stations using EIL (Electronic Instruments Ltd.) instrument systems. At two other locations (N135 and N134), NERA (New England Research Associates Inc.) instrument systems recorded dissolved oxygen, temperature, conductivity, pH and redox potential at half-hourly intervals (Draper et al, 1980). Data collected at these stations were used to calibrate and verify the Grand River Simulation Model (GRSM) and to assess the impacts of various pollution sources including urban runoff on the water quality of the Grand River.

4. CHARACTERISTICS OF URBAN RUNOFF

Since the PLUARG monitoring program was established to collect flow quantity and quality data for the estimation of annual pollutant loads, intensive sampling was not conducted at the monitoring stations during each storm event. As such, detailed runoff quality

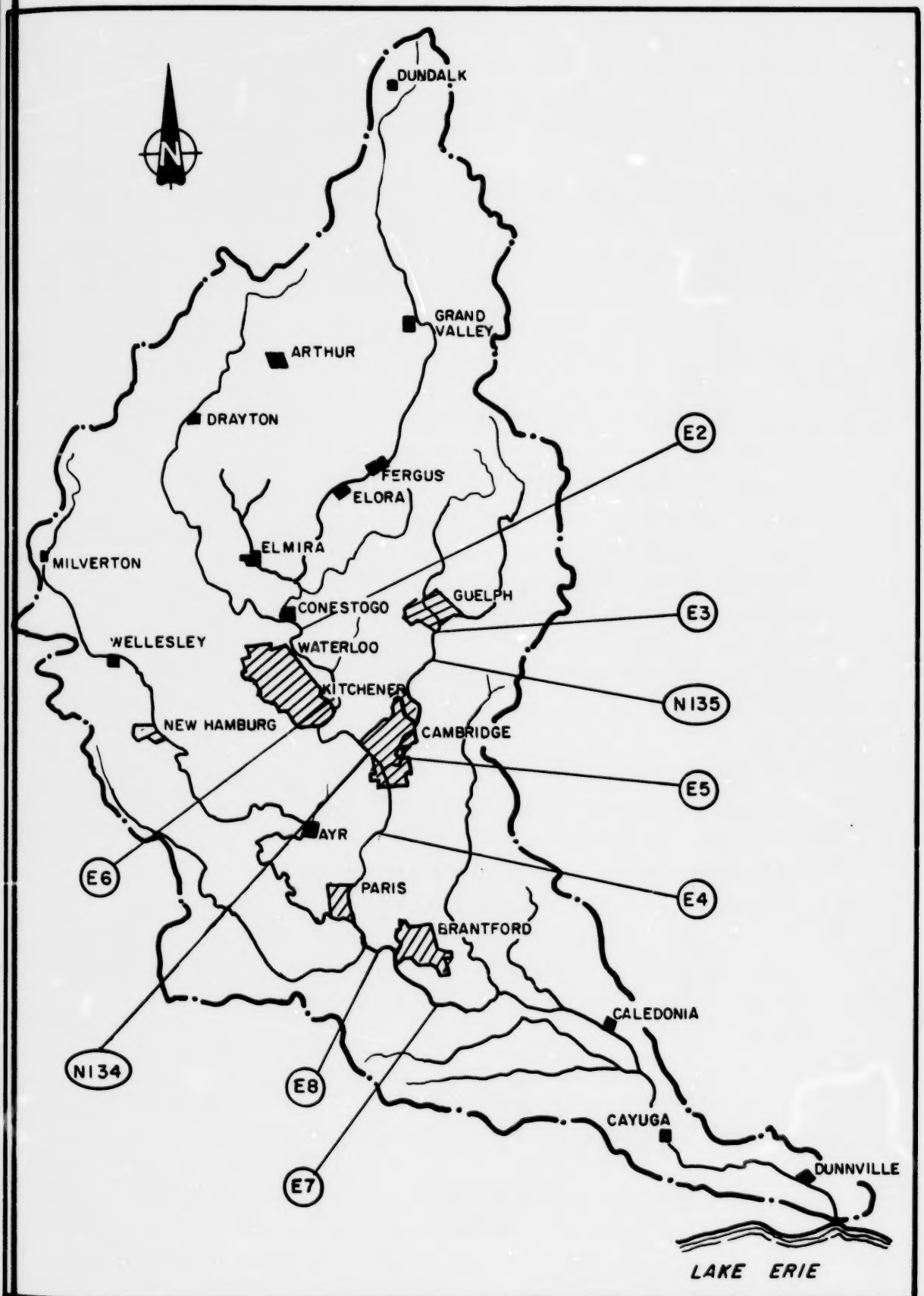

Figure 11 : Continuous Monitoring Network in the Grand River Basin

data are available only for a few storm events which occurred in the sampling period. For this reason, the characterization of urban runoff from the four test catchments relied primarily upon data generated from the other two monitoring programs. A statistical summary of the runoff quality data obtained is presented in Table 2.

Table 2 indicates that the quality data collected in each of the four test catchments span several orders of magnitude. These wide variations are in agreement with the characteristics of urban runoff reported for other cities in Ontario (Weatherbe and Novak, 1977) and can be attributed to the large number of factors known to affect the quality of urban runoff.

It can be seen in Table 2 that the concentrations of suspended solids and total phosphorus were highest in the runoff from the Schneider Creek watershed. The high suspended solids concentrations can be attributed to construction activities in progress in the watershed during the monitoring period while the elevated concentration of phosphorus can be explained by the attachment of phosphorus on sediment particles. For undetermined reasons, the concentrations of five-day biochemical oxygen demand were higher for the two test catchments in Guelph than in the Schneider Creek and Montgomery Creek watersheds.

A comparison between the dry-weather and wet-weather data indicates that the concentrations of the monitored water quality parameters increased when streamflow increased. However, only weak correlations were found during storm events between flow rates and the concentrations of the monitored water quality parameters. Typical runoff hydrographs and pollutographs* obtained from the Schneider Creek and Montgomery Creek watersheds are shown in Figures 12 and 13. Specifically, the first flush phenomenon** was not

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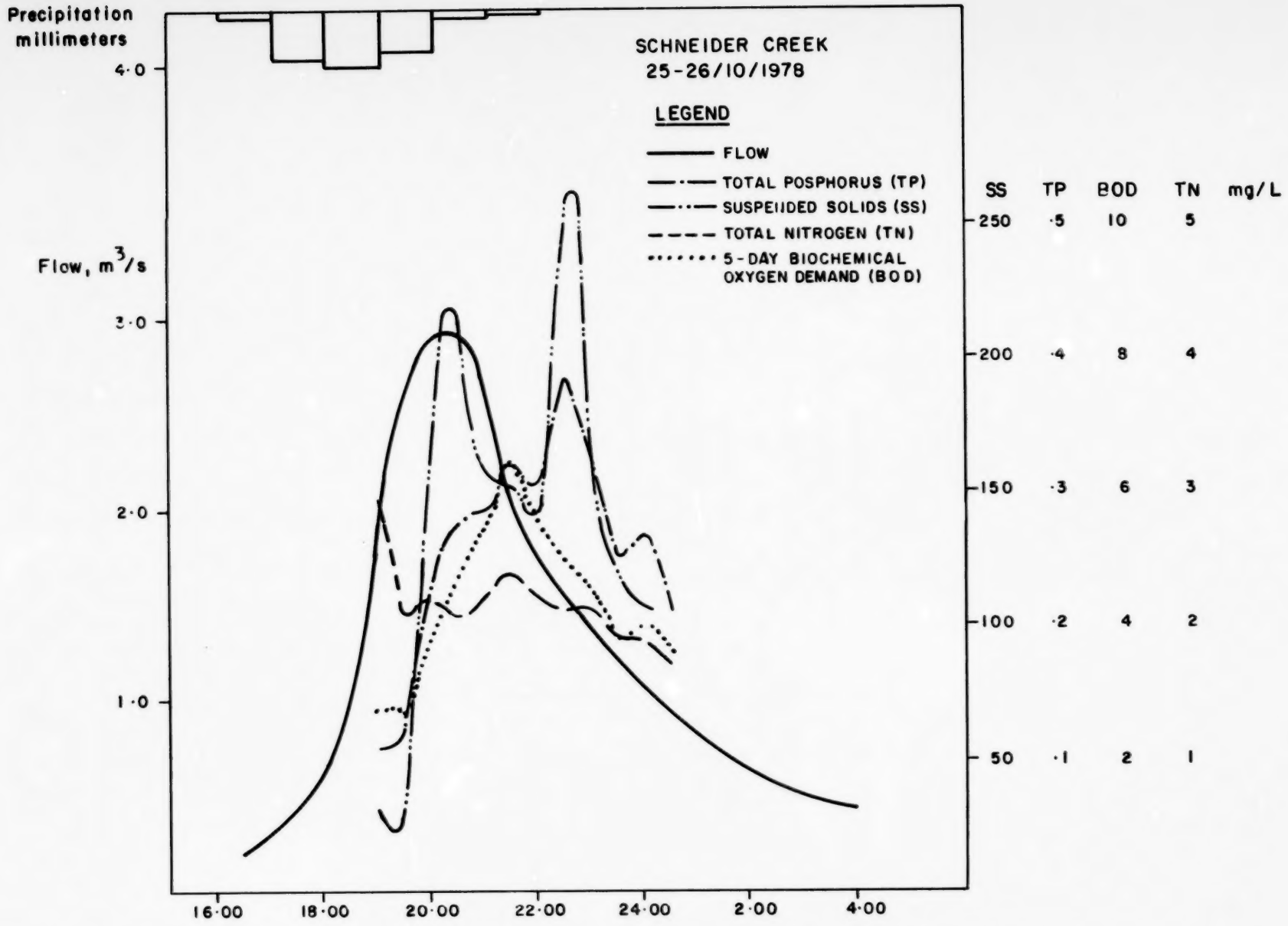
* A pollutograph is a graph that shows the variations of a water quality parameter in time.

** The first flush phenomenon refers to the sharp increase in pollutant concentrations during the beginning of a storm event, with the peak pollutant concentration occurring before the peak runoff.

Table 2. Summary of Urban Runoff Quality Data

	Suspended Solids	5-day Biochemical Oxygen Demand	Total Phosphorus	Total Nitrogen	Lead	Zinc	Chloride
1. SCHNEIDER CREEK WATERSHED							
Mean mg/L	267	3.9	0.66	3.04	0.08	0.78	66
Standard Deviation, mg/L	643	2.5	1.10	2.19	0.07	0.71	36
Range, mg/L	5-4791	0.6-13.0	0.07-9.60	1.21-20.15	0.01-0.35	0.02-3.20	10-175
Number of Samples	128	128	127	124	117	117	124
2. MONTGOMERY CREEK WATERSHED							
Mean, mg/L	81	3.1	0.19	2.50	0.14	0.18	61
Standard Deviation, mg/L	65	2.2	0.10	1.21	0.09	0.15	45
Range, mg/L	19-445	0.2-9.5	0.06-0.64	0.96-7.10	0.01-0.40	0.03-1.00	8-188
Number of Samples	87	87	86	86	72	73	86
3. NORTH CATCHMENT, GUELPH							
Mean, mg/L	77	10.2	0.20	2.30	-	-	-
Range, mg/L	10-1090	0.2-60	0.04-1.60	0.40-5.30	-	-	1-68
4. WEST CATCHMENT, GUELPH							
Mean, mg/L	195	13.9	0.35	3.70	-	-	-
Range, mg/L	5-756	0.2-95	0.03-2.40	0.2-3.4	0.01-0.65	-	0-383


Precipitation
millimeters
4·0
SCHNEIDER CREEK
25-26/10/1978
LEGEND
FLOW
TOTAL POSPHORUS (TP)
SUSPENDED SOLIDS (SS)
TOTAL NITROGEN (TN)
5-DAY BIOCHEMICAL
OXYGEN DEMAND (BOD)
Flow, m3/s
3·0
2·0
1·0
SS TP BOD TN mg/L
250 ·5 10 5
200 ·4 8 4
150 ·3 6 3
100 ·2 4 2
50 ·1 2 1
16·00
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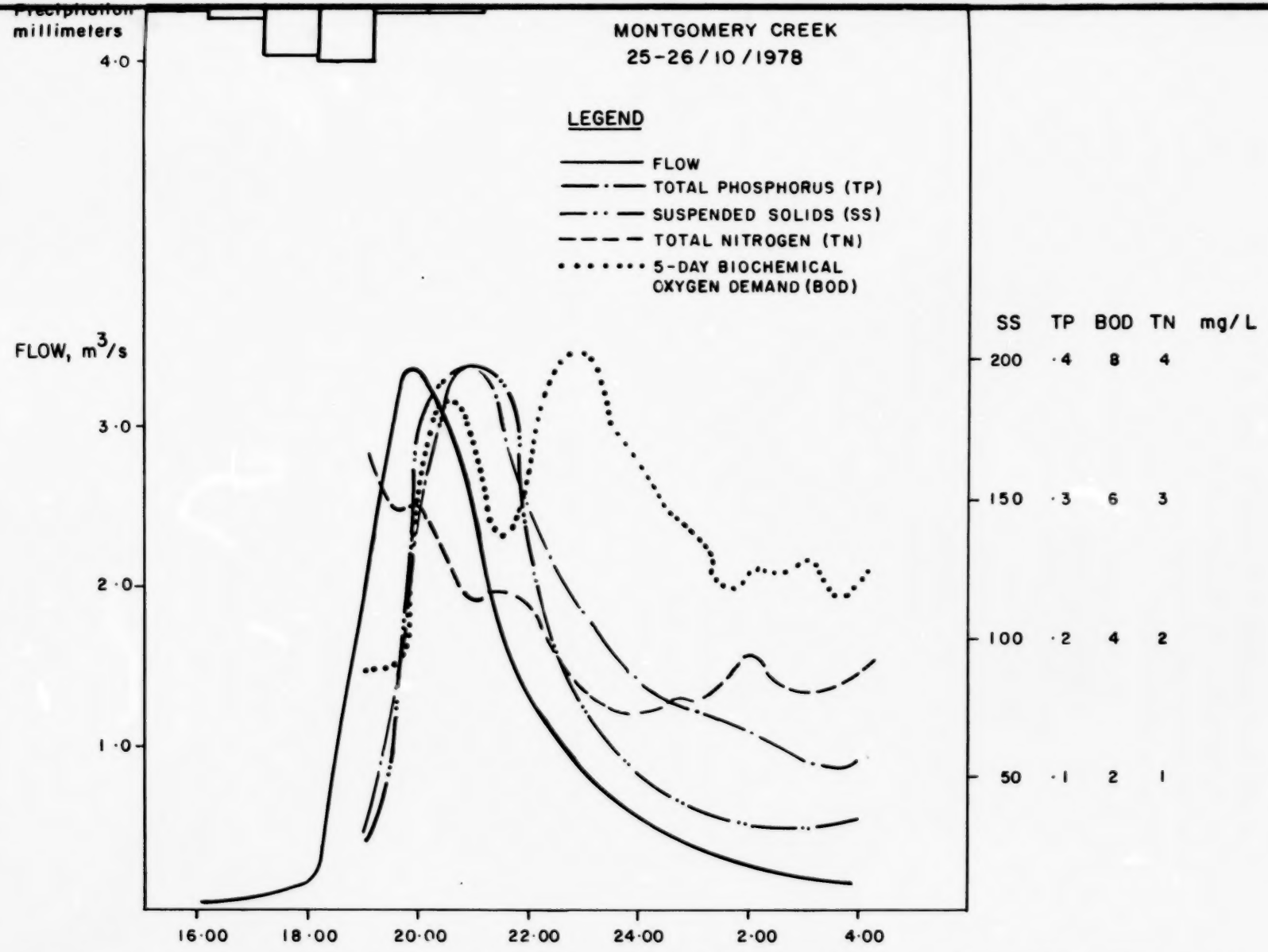

Figure 13 : Hydrograph and Pollutographs of Suspended Solids, 5-Day Biochemical Oxygen Demand, Total Phosphorus and Total Nitrogen as Measured at the Outlet of Montgomery Creek on 25-26/10/1978

observed in either watershed for suspended solids, total phosphorus and five-day biochemical oxygen demand. The first flush phenomenon might have occurred for total nitrogen although available data are not conclusive. In contrast, this phenomenon was reported for suspended solids, five-day biochemical oxygen demand, total phosphorus, and total nitrogen in the two smaller catchments in Guelph (Novak, in press). Apparently the quick hydrologic response of a small catchment favours the occurrence of the first flush phenomenon.

A correlation analysis was performed using the wet-weather water quality data collected from the Schneider Creek and Montgomery Creek watersheds. Relatively strong correlation (coefficient of correlation $r = 0.80$) was found between suspended solids and total phosphorus but not among the other water quality parameters.

The effects of total event precipitation, total runoff volume and length of the antecedent dry period on event pollutant loads were analyzed using data collected in the Schneider Creek watershed. Total event precipitation and total runoff volume were found to be the most dominant factors which determine the event pollutant loads.

5. SIMULATION OF URBAN RUNOFF QUANTITY AND QUALITY

The two objectives of urban runoff simulation are:

1. to provide input data to the GRSM model in terms of urban runoff volumes and pollutant loads on an event basis from the cities of Brantford, Cambridge, Guelph, Kitchener and Waterloo; and
2. to extrapolate urban runoff pollutant loads for the populations projected for the five cities to the years 2001 and 2031.

An evaluation of several urban runoff models with respect to the above objectives lead to the selection of the STORM model (U.S. Army Corps of Engineers, 1977). STORM can simulate both the quantity and quality of urban runoff. It is designed for use with many years of continuous hourly precipitation records but can also be used for individual storm events. The model employs an accounting scheme that, for each storm event, allocates runoff volumes to storage and treatment and notes those volumes exceeding storage or treatment capacities. Water quality is handled as a function of hourly runoff rates, with generated quantities of pollutants allocated to storage, treatment or release into receiving waters. Statistics are generated for each event and collectively for all events processed, including average annual runoff and pollutant loadings. The results of model calibration and verification, with respect to both runoff quantity and quality, are presented in the following sections.

5.1 RUNOFF QUANTITY

Fourteen storm events recorded in the Montgomery Creek watershed were used to calibrate the STORM model with respect to total event runoff volume. The precipitation for these events ranged from 5.3 to 24.1 mm (Table 3) and their durations ranged from 3.5 to 16 hours. This range of event precipitation allows a meaningful assessment of runoff response of an urban area.

The simulation results (Figure 14) compare well with the measured event runoff volumes. About 79% of the deviations - the difference between simulated and measured runoff volumes - are less than 25% of the measured runoff volume. Most of the large deviations are associated with minor storm events for which measurement errors are large relative to the event runoff volume.

The coefficients of imperviousness assigned to the various urban land uses were identified to be the most significant factors which determine the event runoff volume. In order to obtain a good agreement between simulated and measured event runoff volumes, it was found necessary to use relatively low imperviousness values. The coefficient of imperviousness was reduced to 15% for residential land use. This low imperviousness value appears to be reasonable since most of the roof leaders in the Montgomery Creek watershed are not connected directly to the storm sewer system.

Table 3. Results of Runoff Volume Calibration, Montgomery Creek Watershed

Date Rainfall Event Occurred	Rainfall mm	Measured Runoff Volume mm	Simulated Runoff Volume mm
26/07/78	8.7	0.8	1.0
27/07/78	8.9	1.3	1.0
09/08/78	9.7	0.8	0.5
16/08/78	8.1	0.7	0.8
19/08/78	14.5	1.8	2.0
24/08/78	5.3	0.6	0.5
28/08/78	5.3	0.4	0.5
30/09/78	7.4	0.9	0.8
03/10/78	21.8	3.0	4.0
05/10/78	8.4	0.6	0.5
25/10/78	11.2	1.0	1.0
13/11/78	19.8	2.7	3.0
17/11/78	24.1	3.8	4.0
23/11/78	15.0	2.2	2.0
Mean	12.0	1.5	1.5
St. Dev.	6.0	1.1	1.3

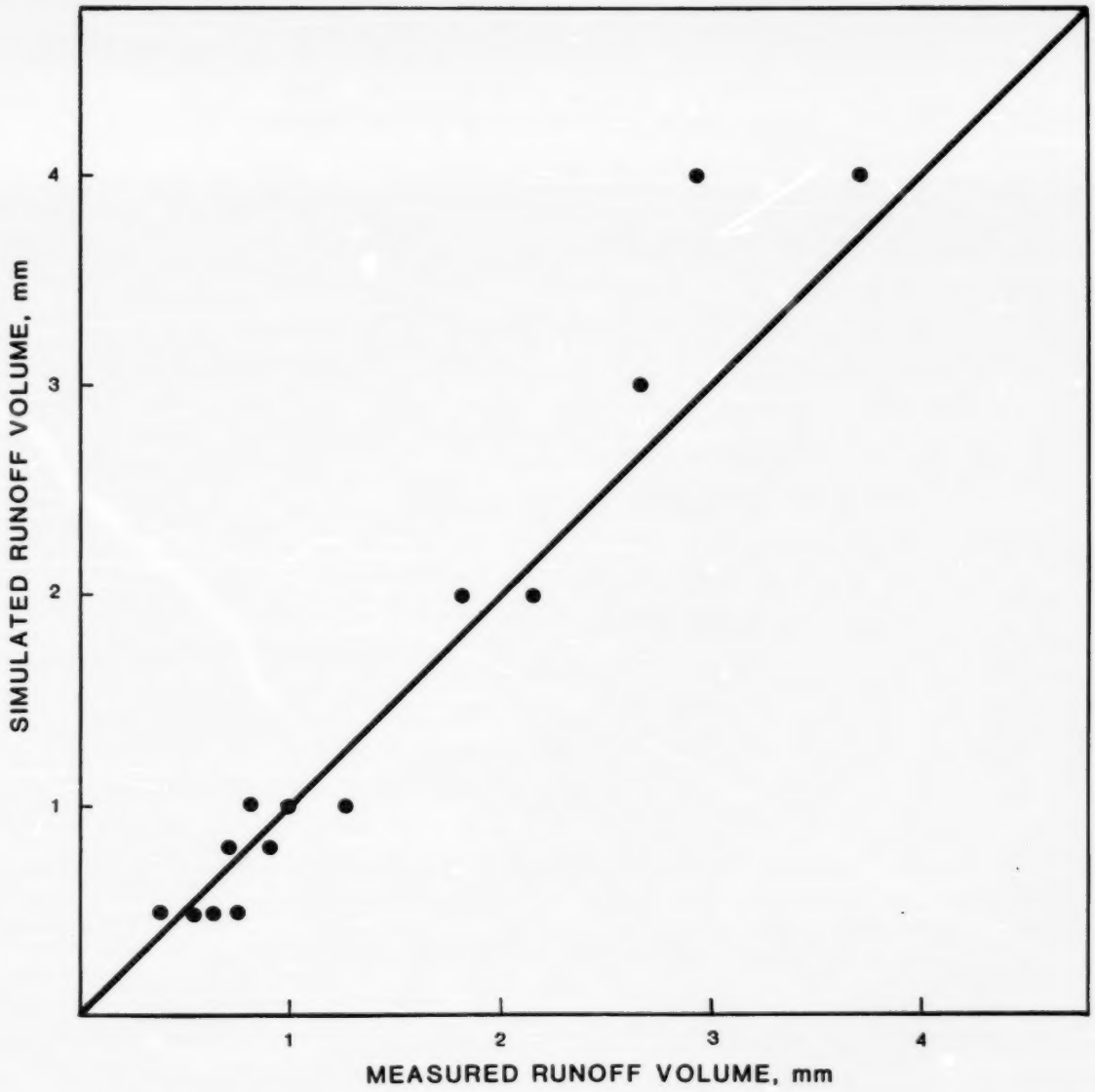

Figure 14 : STORM Model Calibration With Respect to Event Runoff Volume, Montgomery Creek Watershed

For model verification, the calibrated model for the Montgomery Creek watershed was used to simulate the quantity of urban runoff from the Schneider Creek watershed. The calibrated model was adjusted to reflect the characteristics and urban land use distribution in the Schneider Creek watershed. The simulation results (Table 4, Figure 15) are in close agreement with the measured event runoff volumes. About 50% of the deviations are less than 25% of the measured runoff volume.

5.2 RUNOFF QUALITY

Although runoff quality data were collected for most of the storm events recorded in the Montgomery Creek watershed (14 events), complete pollutographs are available for only four events. These events were used to calibrate the STORM model in terms of event pollutant loads. The results are given in Table 5.

The results are acceptable, particularly when one considers the simplistic approach used by the STORM model to simulate the quality of urban runoff. In most cases, the simulated event pollutant loads are within $\pm$ 50% of the measured loads.

During model calibration, it was found that the simulated event pollutant load depends primarily on three sets of parameters: the pollutant accumulation rates, the characteristics of dust and dirt and the washoff exponent. The effect of the washoff exponent on the shape of the simulated pollutograph, however, was found to be small.

The calibrated model was used to simulate the quality of urban runoff for the Schneider Creek watershed. As mentioned earlier, the model was adjusted to reflect the characteristics and urban land use distribution in the Schneider Creek watershed. The measured and simulated event pollutant loads are compared in Table 6.

On the whole, the simulated event pollutant loads compare well with the measured loads; both are of the same order of magnitude. The results are particularly good for total phosphorus and total nitrogen; the simulated event loads are within $\pm$ 50% of the measured loads. The results are not as good for suspended solids and five-day biochemical oxygen demand.

Table 4. Results of Runoff Volume Verification, Schneider Creek Watershed

Date Rainfall Event Occurred	Rainfall mm	Measured Runoff Volume mm	Simulated Runoff Volume mm
03/07/78	13.5	0.8	1.0
21/07/78	10.2	0.5	0.8
22/07/78	4.6	0.2	0.3
26/07/78	8.6	0.5	0.5
02/08/78	5.8	0.3	0.3
09/08/78	6.6	0.5	0.3
16/08/78	7.4	0.4	0.5
24/08/78	5.8	0.6	0.3
28/08/78	6.1	0.3	0.3
29/08/78	7.6	1.0	0.5
02/09/78	4.6	0.2	0.3
11/09/78	22.4	2.2	2.0
14/09/78	20.6	2.5	2.0
30/09/78	4.8	0.2	0.3
03/10/78	22.6	2.2	2.5
05/10/78	8.4	0.7	0.8
25/10/78	16.5	1.6	2.0
13/11/78	18.0	1.8	2.0
17/11/78	25.4	2.9	2.5
23/11/78	17.0	1.9	1.0
Mean	11.3	1.1	1.0
St. Dev.	7.2	0.9	0.8

TABLE 5. Result of Event Pollutant Calibration, Montgomery Creek Watershed

Date Storm Event Occurred	Suspended Solids kg		5-day Biochemical Oxygen Demand kg		Total Phosphorus kg		Total Nitrogen kg	
	Measured	Simulated	Measured	Simulated	Measured	Simulated	Measured	Simulated
03/10/78	1909	2849	109	178	5.3	7.0	120	151
05/10/78	176	296	8	17	0.6	0.8	32	15
25/10/78	1619	1362	78	93	3.3	3.3	66	73
23/11/78	2768	2889	26	167	5.4	7.1	158	151

TABLE 6. Result of Event Pollutant Calibration ,Schneider Creek Watershed

Date Storm Event Occurred	Suspended Solids kg		5-day Biochemical Oxygen Demand kg		Total Phosphorus kg		Total Nitrogen kg	
	Measured	Simulated	Measured	Simulated	Measured	Simulated	Measured	Simulated
16 /08/78	906	2711	72	186	6.3	6.7	112	146
24 /08/78	2033	1800	106	120	5.5	4.4	104	97
14 /09/78	18383	12781	254	703	43.3	31.6	390	661
17 /09/78	372254	104926	1001	5006	857.0	258.8	3592	5307
30 /09/78	1684	670	47	39	2.6	1.7	46	35
30 /10/78	21924	8786	453	489	48.2	21.6	434	459
5-6/10/78	1843	2513	24	132	4.7	6.2	106	130
25 /10/78	5750	5613	171	325	10.5	13.9	182	295
13 /11/78	12473	7522	488	478	26.6	18.6	392	399
23 /11/78	21268	6950	71	384	30.2	17.1	376	361

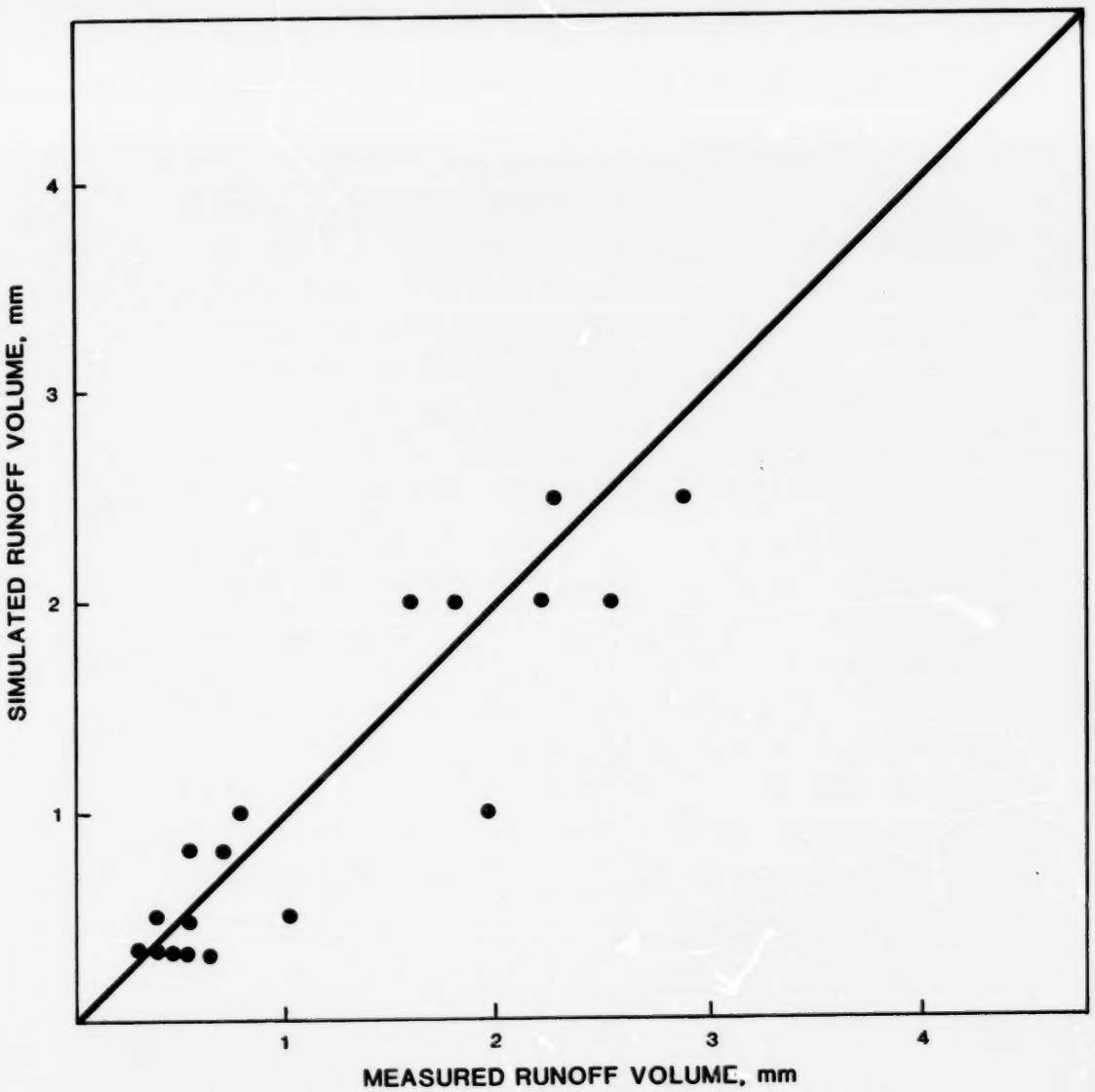

Figure 15 : STORM Model Verification With Respect to Event Runoff Volume. Schneider Creek Watershed

5.3 LONG-TERM SIMULATION

The STORM model was used to simulate the urban runoff and associated pollutant loads for the cities of Brantford, Cambridge, Guelph, Kitchener and Waterloo for a 20-year period (1956-1975). For each city, the model was adjusted to reflect the characteristics and urban land use distribution. Parameter values for the pollutant accumulation rates, the characteristics of dust and dirt and the washoff exponent were the same as used in the calibrated model. A statistical summary of the simulation results is presented in Table 7. The urban contributions of suspended solids, total phosphorus and total nitrogen are relatively small (2% - 6% of the total Grand River basin load) when compared with the loadings from agricultural sources and sewage treatment plants (So and Singer, 1982).

The STORM model was also used to simulate the urban runoff and associated pollutant loads for three future land use profiles developed for the cities of Brantford, Cambridge, Guelph, Kitchener and Waterloo. These three profiles consider a medium population projection for the year 2001 and medium and high population projections for the year 2031 (Veale, 1981). Table 8 gives a comparison between the simulated pollutant loads under present conditions and those obtained for the three projected future land use profiles. Whereas the unit-area loads of suspended solids, biochemical oxygen demand, total nitrogen, and total phosphorus remain the same, a substantial increase in the total loads from the four cities is indicated.

In order to evaluate the impact of future increased urbanization on the Grand River, a strategy was adopted to evaluate the impact of the high population projection for the year 2031. If the impact at that level is found to be negligible, there would be no need to evaluate the other two, less extreme, population projections. The less extreme profiles would be evaluated if that was not the case. This was done to avoid redundant analysis.

Table 7. Summary of Simulation Results for the Period 1956 - 1975

	Brantford	Cambridge	Guelph	Kitchener	Waterloo
Area, ha	3214	3675	3080	5242	2622
Runoff as Fraction of Precipitation	0.17	0.19	0.19	0.15	0.15
Average Pollutant Loads, kg/ha/year					
Suspended Solids	227.8	266.9	215.4	184.6	184.6
5-day Biochemical Oxygen Demand	11.8	13.8	11.1	9.6	9.6
Total Nitrogen	11.7	13.7	11.1	9.5	9.5
Total Phosphorus	0.6	0.6	0.5	0.4	0.4

Table 8. Simulated Pollutant Loads for Four Urban Land Use Profiles

	1976	2001 Medium Population Projection	2031 Medium Population Projection	2031 High Population Projection
1. Brantford				
Population, capita	66930	94982	144565	180485
Developed area, ha	3214	4685	6684	8117
Population Density, capita/ha	20	20	22	22
SS*, t/year (kg/ha/year)	732.8 (227.8)	1287.1 (274.6)	1979.4 (296.0)	2476.6 (304.9)
BOD, t/year, (kg/ha/year)	38.0 (11.8)	66.8 (14.2)	102.5 (15.3)	128.1 (15.8)
TN, t/year (kg/ha/year)	37.8 (11.7)	66.3 (14.1)	101.9 (15.2)	127.5 (15.7)
TP, t/year (kg/ha/year)	1.8 (0.6)	3.1 (0.7)	4.8 (0.7)	6.0 (0.7)
2. Cambridge				
Population, Capita	71482	124474	178662	205495
Developed Area, ha	3675	5307	7408	8431
Population Density, capita/ha	19	23	24	24
SS*, t/year (kg/ha/year)	981.5 (266.9)	1384.4 (260.7)	1982.1 (267.4)	2283.8 (270.7)
BOD, t/year, (kg/ha/year)	50.8 (13.8)	71.2 (13.4)	101.9 (13.8)	117.3 (13.9)
TN, t/year (kg/ha/year)	50.5 (13.7)	71.4 (13.4)	102.2 (13.8)	117.7 (14.0)
TP, t/year (kg/ha/year)	2.4 (0.6)	3.3 (0.6)	4.8 (0.6)	5.5 (0.7)
3. Guelph				
Population, capita	70374	122206	215883	280419
Developed Area, ha	3080	5525	9005	11364
Population Density, capita/ha	22	22	24	25
SS*, t/year (kg/ha/year)	663.7 (215.4)	1402.0 (253.6)	2458.9 (272.9)	3165.0 (278.4)
BOD, t/year, (kg/ha/year)	34.1 (11.1)	72.9 (13.2)	127.5 (14.1)	163.8 (14.4)
TN, t/year (kg/ha/year)	34.2 (11.1)	72.2 (13.1)	126.8 (14.1)	163.2 (14.4)
TP, t/year (kg/ha/year)	1.6 (0.5)	3.4 (0.6)	5.9 (0.7)	7.6 (0.7)
4. Kitchener-Waterloo				
Population, capita	181773	326617	463577	531399
Developed Area, ha	7864	13197	18361	20881
Population Density, capita/ha	23	25	25	25
SS*, t/year (kg/ha/year)	1452.8 (184.6)	3913.2 (296.4)	5617.6 (305.8)	6471.0 (309.7)
BOD, t/year, (kg/ha/year)	75.6 (9.6)	201.6 (15.3)	289.2 (15.7)	333.1 (15.9)
TN, t/year (kg/ha/year)	74.9 (9.5)	201.6 (15.3)	289.5 (15.8)	333.5 (16.0)
TP, t/year (kg/ha/year)	3.5 (0.4)	9.4 (0.7)	13.6 (0.7)	15.6 (0.7)

* SS: suspended solids, BOD: biochemical oxygen demand, TN: total nitrogen, TP: total phosphorus

6. IMPACTS OF URBAN STORMWATER RUNOFF ON THE GRAND RIVER

6.1 GENERAL REVIEW

Untreated stormwater runoff may contribute a significant portion of the total pollutant load entering receiving waters on an annual basis, and are often significant on a shock-load basis during wet events. Waller and Novak (1979) estimated that stormwater runoff accounts for 59% of the suspended solids and 18% of the biochemical oxygen demanding materials discharged annually to the Great Lakes from municipal sources in Ontario. Rimer and Nisse (1978) found that stormwater runoff generally depressed the DO level in the Neuse River below the low flow antecedent level by about 1 mg/l and generally for less than one day. Pitt and Amy (1973) reported that the immediate toxic effects of urban runoff are most likely due to extreme oxygen demand and, in a simulation, showed that approximately two-thirds of the BOD was exerted during the first day after runoff. Colston (1974) concluded in his Durham, N.C. study that 40-50% of the chemical oxygen demand in urban runoff was susceptible to biodegradation in 20 days.

Receiving waters such as streams, lakes and estuaries differ in the manner in which they react to similar pollutant loadings. Further, the types, extents and rates of water quality processes that occur in water bodies are controlled by the immediate physical environment as defined by climate and physiography. For example, one of the unique characteristics of a river is that the water column is continually subjected to a new benthic or attached biotic community by virtue of the fact that the water column continually moves downstream. This system is much different from lakes where overlying water column remains in contact with the same benthic community in a given location. If the intensity of the pollution is not too great and the duration is not too long, the benthic community in the river will be relatively unaffected by the movement of the pollutant through the system. On the other hand, the plankton will be directly affected by the wasteload, since they will tend to move downstream with it. The reaction of these biota to the pollutant load depends on the initial concentrations of the pollutants and the length of time it takes before the processes of dispersion or biological decay can reduce concentrations to acceptable limits (Roesner, 1979).

The response of a receiving water to a waste load depends also on the conditions of the receiving water immediately upstream of the point of waste load introduction. These conditions include flow, water temperature, dissolved oxygen concentrations and biochemcial oxygen demand. Thus, the particular response of the receiver under different initial states is basically a matter of defining the appropriate boundary conditions at the time the waste load is imposed.

When pollutants from urban runoff are discharged into receiving waters, they may affect the water quality in several ways. Some of their impacts are immediate, such as bacterial contamination. Others are long-term impacts, such as nutrient enrichment which may lead to eutrophication. Further, these impacts can be viewed in terms of major pollutants (oxygen demanding materials, suspended solids and associated contaminants, nutrients, heavy metals and bacteria) and their specific effects on the various uses of the receiving water (Singer, 1982).

6.1.1 OXYGEN DEMANDING MATERIALS

The dissolved oxygen concentration is one of the most important water quality parameters which is used to evaluate the impact of oxygen demanding materials on receiving waters. Oxygen demanding materials contributed by urban runoff could pose a serious problem if they deplete the oxygen resources of the receiving waters. For example, under conditions of low flow, high temperature and point source discharges, the initial DO level in a stream tends to be low. As urban runoff from a storm event begins to enter the stream, the effects of increased flow tend to drive the DO concentration up. Downstream from the urban area, however, the oxygen demanding materials washed into the stream begin to exert themselves and an oxygen sag of varying magnitude and duration develops. The oxygen depletion might be severe enough to render the receiving water unfit for a healthy aquatic life.

6.1.2 SUSPENDED SOLIDS

Urban runoff often has suspended solids concentrations higher than or equal to those of raw sewage. The sources of suspended solids are erosion, emissions from motor vehicles, atmospheric fallout and construction activities. Many studies revealed that the largest single contributing factor to the generation of suspended solids in urban areas is construction. In a literature survey of urbanizing areas, Chen (1974) found that soil erosion rates for construction areas ranged from 50 to 200 tons per acre per year.

Suspended solids are considered as a pollutant for reasons that are less obvious than some other materials which degrade water quality. Suspended solids which find their way into receiving waters may be deposited and become sediment. Sediment is a nuisance if deposited in navigation channels and it can choke drainage ways by reducing their capacity to carry high flows. Suspended solids can also result in the clogging of gills of fishes and sediment may impair or destroy fish spawning areas.

High concentrations of suspended solids increase water turbidity and reduce the light penetration of water. High turbidity adversely affect water uses such as swimming and drinking. On the other hand, reduced light availability, caused by high turbidity, lowers the rate of the photosynthesis process. This in turn reduces the density of aquatic plants and algae in the receiving water, thus resulting in a positive effect on the dissolved oxygen regime.

A major impact of suspended solids as a pollutant is related to their ability to serve as a vehicle to carry other pollutants such as heavy metals, pesticides, trace organics, and phosphorus into receiving waters (O'Neill, 1979).

6.1.3 NUTRIENTS

Nutrient input to receiving waters is a contributing factor to the deterioration of water quality. Nutrient enrichment may lead to serious problems for aquatic communities. Accelerated biomass production results in obnoxious algal blooms which may cause taste and odour problems in water supplies, form surface scums in quiescent waters, inhibit swimming and recreation, and may be toxic to small mammals drinking the water.

In most inland water bodies and the Great Lakes, phosphorus is the controlling nutrient. The level of algal production is directly dependent upon the amount of phosphorus in a lake. In some forms, phosphorus is immediately available as a nutrient and promotes the growth of algae and other aquatic plants, whereas other forms of phosphorus may settle to the bottom sediments. While phosphorus in bottom sediments is relatively unavailable to aquatic plants and algae, it may be transformed to available forms and re-introduced into lake waters when oxygen is absent in the bottom waters (Tanner, 1979).

6.1.4 TRACE CONTAMINANTS

Trace contaminants include substances such as heavy metals, pesticides and industrial organic compounds that may occur in water in the parts per billion range or less. If present in sufficient concentrations, these contaminants can affect adversely fish and other aquatic organisms. Contaminants such as mercury and some organic compounds such as mirex and polychlorinated biphenyls (PCBs) can bioaccumulate in fish to the point where human consumption should be restricted or stopped. Elevated levels of trace contaminants can affect the suitability of water for municipal water supply or agricultural uses.

Several types of heavy metals have been found in urban runoff. The most common ones are lead, zinc and copper. Other metals, such as cadmium, chromium, iron, mercury and nickel are present in trace amounts.

Pesticides, including herbicides, fungicides, and insecticides are used for insect and weed control in both rural and urban areas and are found in runoff from both types of areas and in sewage treatment plant discharges. Industrial organic compounds are used virtually everywhere. Electrical equipment, paints, solvents, caulking compounds, printing ink, plastics, cosmetics and pharmaceuticals are only a few of the products in which industrial organics have been used. Because of their widespread use, these compounds are present in sewage treatment plant discharges and land drainage, most notably from urban areas.

6.1.5 BACTERIA

Bacterial contaminants in urban areas can originate as the result of ineffective chlorination at sewage treatment plants, illegal discharges of sanitary wastes to storm sewers or directly to watercourses, or from urban stormwater runoff which is contaminated by fecal matter from wild animals and pets.

Microbiological studies of storm water runoff and combined sewer overflows reveal the existence of high counts of indicator bacteria (total coliforms, fecal coliforms, fecal streptococci), pathogenic bacteria (Pseudononas aeruginosa, Salmonella sp.), total fungi and parasites. Bacterial input from urban areas may constitute a health hazard and result in restrictions on swimming and other recreational activities.

Qureshi (1978) investigated the microbiological characteristics of storm water runoffs at East York (Toronto) and Guelph and found them to contain significant quantities of fecal pollution indicator bacteria. The total coliform densities ranged from 3000 to 1,190,000 per 100 ml. Fecal coliform levels varied from 200 to 560,000 per 100 ml. Fecal streptococci densities were equal to or greater than fecal coliforms and ranged from 3000 to 620,000 per 100 ml.

Qureshi (1978) detected Salmonellae consistently in discharges from the Toronto and Guelph storm sewers. In several instances, these pathogens were readily isolated from as little as 10 ml of storm waters. The salmonella isolates belonged to four different types:

S. haardt, S. saint-paul, S. tennessee and S. typhimurium. Opportunistic pathogenic bacteria viz. Pseudomonas aeruginosa and Staphylococcus aureus were also isolated from runoffs at both storm sewers. The densities of these two organisms varied from 1 to 630 and 1 to 100 per 100ml, respectively. In addition, Qureshi found remarkably high population of fungi at both sites. The concentrations fluctuated from 140,000 to 12,000,000 per 100 ml.

All the above considerations indicate that the question of impacts of urban runoff on receiving waters is an issue which is dependent on specific local conditions. For the purpose of the Grand River Basin Water Management study, the impacts of urban runoff were investigated for the local urban streams, the main channel of the Grand River between Kitchener and Brantford, and the Speed River below Guelph.

6.2 IMPACTS ON LOCAL URBAN STREAMS

Urban runoff has a significant impact on the water quality of the small urban streams such as the Schneider and Montgomery Creeks in Kitchener. Levels of sediment, nutrients, trace contaminants, chloride, and bacteria are generally high in urban streams. The bulk of these pollutants are washed off the urban areas during the spring melt period (50-70%) and during intense rain storms. Data collected during the PLUARG program in the Schneider and Montgomery Creeks (Table 9) indicate that the concentrations of phosphorus, copper, lead, zinc and PCB's exceed MOE Water Quality Objectives (O'Neill, 1979). Additional data collected during the Grand River Basin Water Management study confirmed these PLUARG findings.

6.3 IMPACTS ON THE MAIN GRAND RIVER AND SPEED RIVER

While urban runoff has a significant impact on the water quality of small urban streams because it constitutes a large portion of the flow in these streams, its impacts on the main Grand River and Speed River are not readily obvious. This is due to the fact that urban runoff accounts for small fractions of the flows and pollutant loads in these reaches. The other significant sources of flows and pollutant loads include agricultural runoff, discharges from sewage treatment plants, and industrial effluents. Therefore, it was decided to investigate the impacts of all these inputs, including urban runoff, on the dissolved oxygen regimes in the main Grand River and Speed River. The urban pollutants which were considered in this evaluation were suspended solids, nutrients and biochemical oxygen demand.

Table 9. Mean Pollutant Concentrations in Surface Water at Schneider Creek and Montgomery Creek.

Parameter	MOE Water Quality Objectives		Schneider Creek		Montgomery Creek	
	Concentration mg/l	Use	PLUARG[1]	GRBWMS[2]	PLUARG[1]	GRBWMS[2]
Suspended solids	-	-	-	224	-	80
Biochemical Oxygen Demand	-	-	-	3.9	-	5.0
Phosphorus	.03	F&W[3]	0.028*	0.50	0.080*	0.18
$F(NO_3+NO_2)-N$	10.0	PWS[4]	1.43	1.10	2.18	1.52
Chloride	250	PWS	115	96	175	195
Copper	.005	F&W	0.025*	0.048*	0.012*	0.021*
Lead	.005	F&W	0.050*	0.077*	0.052*	0.116*
Zinc	.03	F&W	0.08*	0.83*	0.05*	0.17*
Chromium	.10	F&W	0.019	0.058	0.009	0.026
Nickel	.025	F&W	0.006	0.020	0.004	0.008
Cadmium	.002	F&W	0.001	0.002	0.001	0.001
Mercury	.002	F&W	0.00009	0.00012	0.00014	0.00006
PCBs	$.001 \times 10^{-3}$	F&W	0.04×10^{-3}*	-	0.024×10^{-3}*	-
DDTs	$.003 \times 10^{-3}$	F&W	0.0002×10^{-3}	-	0.0002×10^{-3}	-
Chlordane	$.06 \times 10^{-3}$	F&W	-	-	0.0004×10^{-3}	-
Dieldrin	$.001 \times 10^{-3}$	F&W	0.0002×10^{-3}	-	0.001×10^{-3}	-
Endrin	$.002 \times 10^{-3}$	F&W	0.0005×10^{-3}	-	0.0003×10^{-3}	-
Heptachlor	$.001 \times 10^{-3}$	F&W	0.0003×10^{-3}	-	0.0004×10^{-3}	-

1 PLUARG data (O'Neill, 1979)

2 Grand River Basin Water Management Study data (MOE, 1978)

3 Fish and Wildlife Protection

4 Public Water Supplies

* Exceeds MOE Water Quality Objectives

The strategy was:

1. to develop a continuous dynamic water quality model capable of accepting inputs from point and non-point (urban and rural) sources and predicting the water quality parameters (mainly DO) under various flow regimes, sewage treatment levels and meteorological conditions;

2. to collect continuous data on DO, temperature and other quality parameters in the Grand River basin in order to calibrate and verify the model; and

3. to use the model in the assessment of the impacts of various inputs including urban runoff and to evaluate water management alternatives in the megalopolis area of the Grand River basin.

6.3.1 THE GRAND RIVER SIMULATION MODEL (GRSM)

This is a dynamic model which utilizes O'Connor and DiToro's formulation for the calculation of DO in river systems. The model accounts for the deficits of DO caused by carbonaceous (BOD) and nitrogenous (NOD) oxygen demand, benthic oxygen demand as well as the replenishment of oxygen due to reaeration. Oxygen production and uptake (photosynthesis and respiration) as well as the day to day and seasonal growth, death and washout of three types of attached aquatic plants are calculated using an ecological subroutine (ECOL) (Kwong *et al*, 1979).

The water quality parameters include DO, BOD, NOD, nitrate, suspended solids and total phosphorus. The dynamic model simulates the effects of sewage treatment plant effluent and urban runoff under different flow conditions. Output of the model provides DO concentrations at each 2-hour time step.

6.3.2 GRSM MODEL CALIBRATION AND VERIFICATION

The GRSM model was calibrated using data obtained on weather, river hydrology, STP effluents and upstream boundary conditions (quality and quantity) for the year 1976, from June to September (Kwong, 1980). The simulated DO concentrations were compared with the continuous monitoring data for Reach No. 8 at Glen Christie below Guelph, Reach No. 12 at Preston and Reach No. 16 at Glen Morris below the Galt STP (Figure 16). Model parameters were adjusted until good agreement was obtained between observed and simulated DO values (Figures 17, 18 and 19).

Actual survey data of 1977 were then used to verify the dynamic model. The verification results indicate that the model is capable of reproducing the observed daily minimum DO within ± 1 mg/L approximately 80% of the time. In general, the accuracy of the predicted minimum DO concentrations is much better than the predicted maximum.

6.3.3 RESULTS OF SIMULATION

The urban loadings were calculated by STORM and input to the dynamic model at five nodes representing the five urban areas: Brantford, Cambridge, Guelph, Kitchener and Waterloo, (Figure 16).

The impact of the urban runoff on the Grand River was evaluated by running the GRSM model twice for the period June-September, 1976. The first run included the urban input from the five cities whereas in the second run, the impact of urban input was nullified by altering the quality of the stormwater input. This was done to maintain the same flow patterns for the two runs.

Negation of the effects of stormwater on water quality was achieved by setting the concentrations of BOD, NOD, NO_3, suspended solids and total phosphorus in urban runoff to minimum values of 0.1 mg/L. A comparison of the results of the two simulation runs (Table 10) indicates that the percent of time in DO violations on the Speed River decreased by a few percentage points when the pollutants in the urban runoff were excluded while the increased flow was maintained. The improvements in the daily minimum DO concentrations

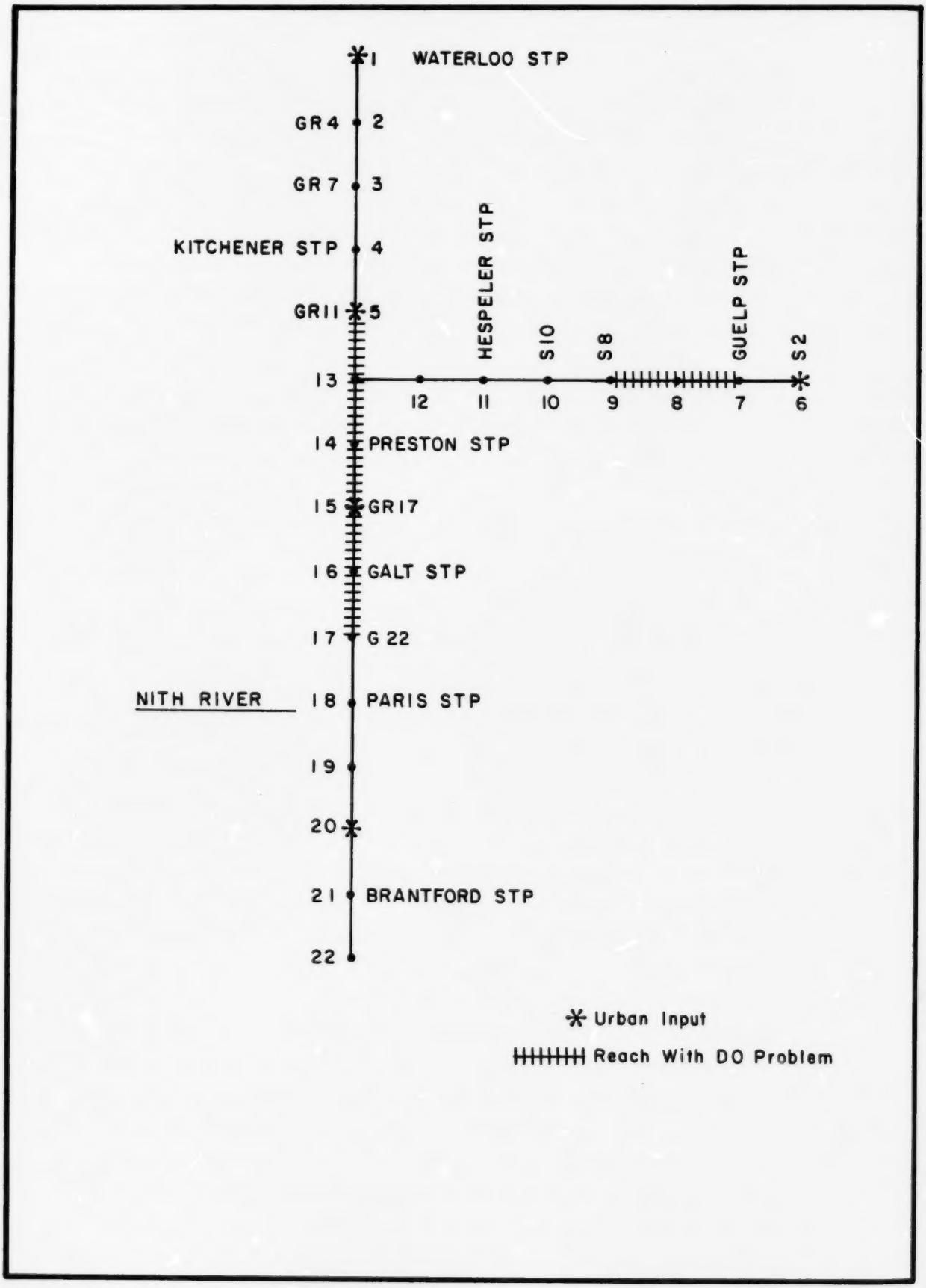

Figure 16 : Grand River Water Quality Simulation Model – Geometry of River System

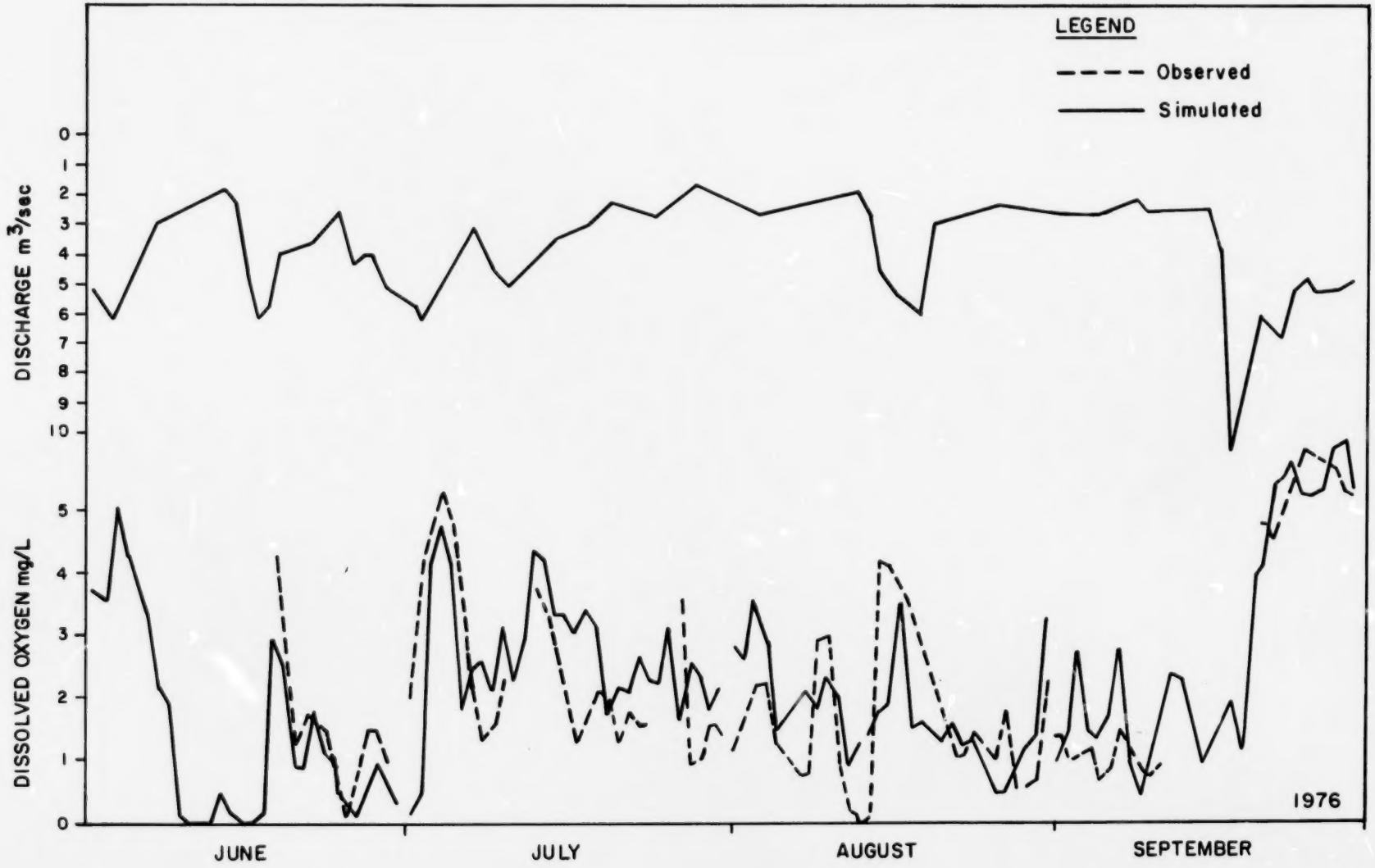

Figure 17 : A Comparison Between Observed and Simulated Daily Minimum Dissolved Oxygen Concentrations For Reach No. 8 at Glen Christie Below Guelph on the Speed River

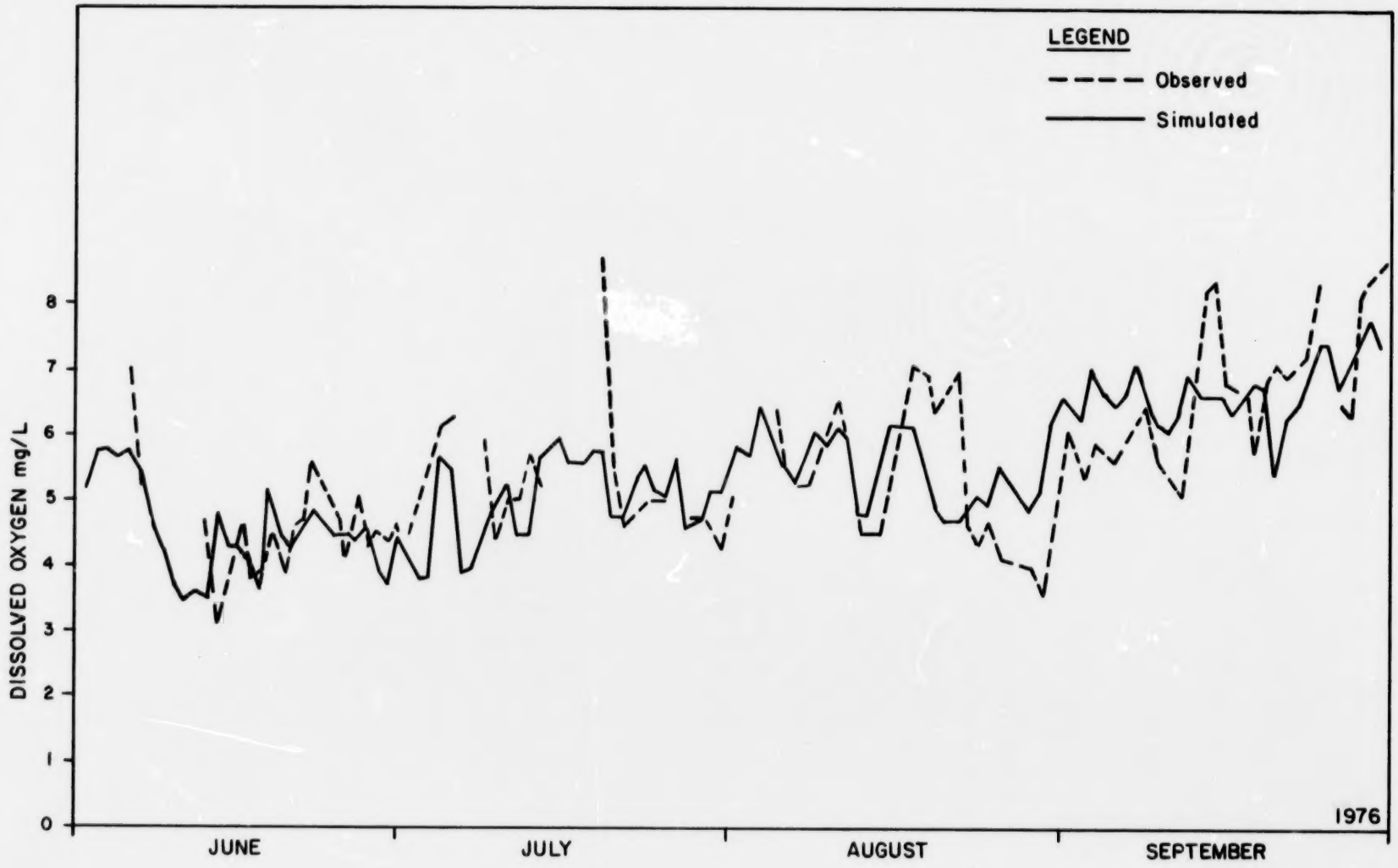

Figure 18 : A Comparison Between Observed and Simulated Daily Minimum Dissolved Oxygen Concentrations For Reach No. 12 at Preston on the Speed River

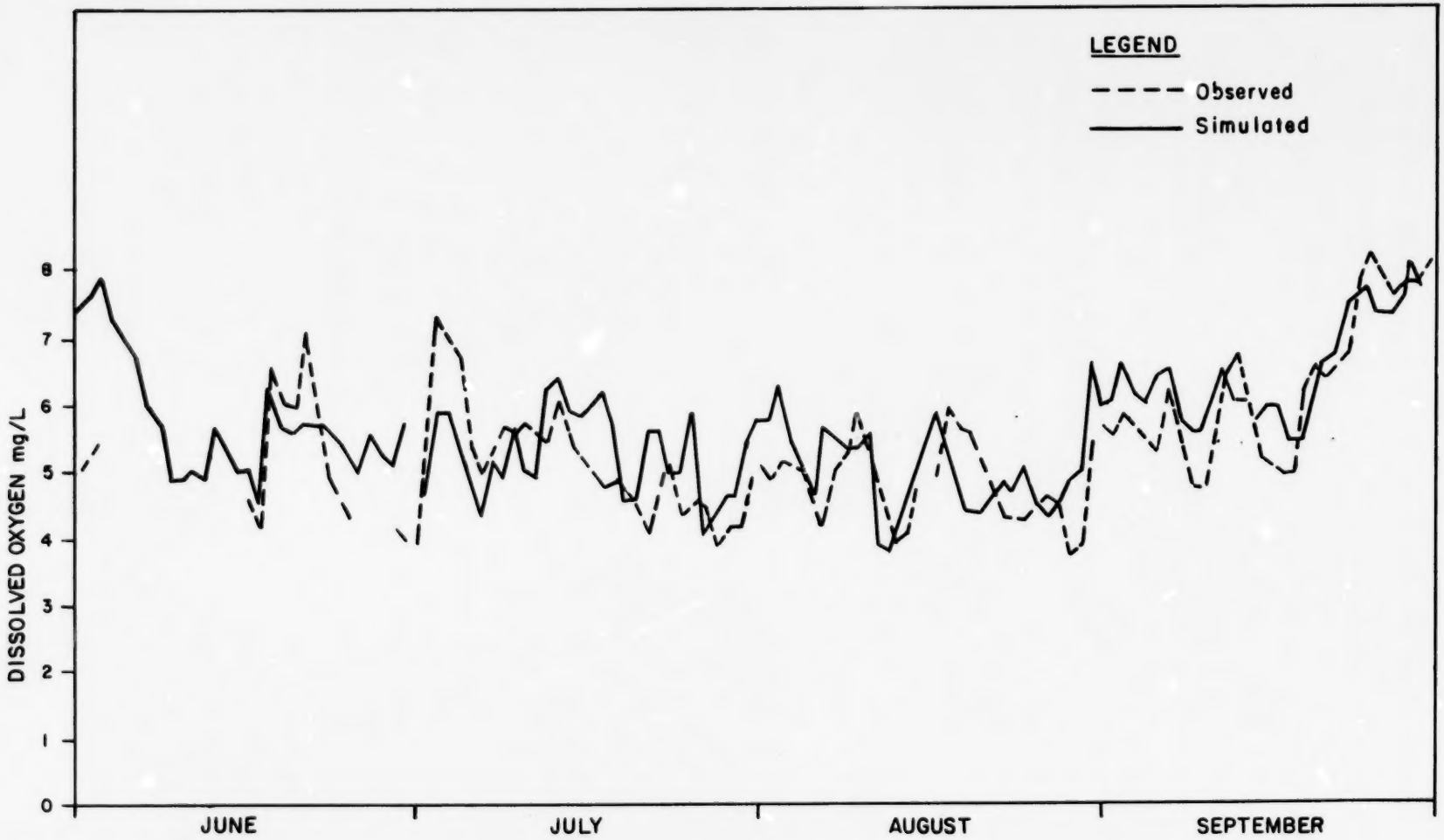

Figure 19 : A Comparison Between Observed and Simulated Daily Minimum Dissolved Oxygen Concentrations For Reach No. 16 at Glen Morris Below Galt STP on the Main Grand River

Table 10. A comparison Between the Results of Two Simulation Runs (with and without Urban Runoff) in Terms of Percent Time in DO Violations for 21 Reaches on the Grand River (June-September, 1976).

LOCATION	REACH	JUNE		JULY		AUGUST		SEPTEMBER	
		Run No. 1*	Run No. 2**	Run No. 1	Run No. 2	Run No. 1	Run No. 2	Run No.1	Run No. 2
Grand River between	1	0.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Bridgeport and the	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Confluence with	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Speed River	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	5	3.6	3.6	4.8	5.9	5.4	10.2	0.0	1.4
Speed River below	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
the Confluence with	7	30.3	28.1	36.8	31.5	43.5	43.5	29.2	28.6
the Eramosa River	8	50.0	48.6	48.7	41.7	56.5	55.9	44.2	38.3
	9	2.5	1.4	7.3	2.7	2.7	5.1	3.9	1.1
	10	21.1	19.2	8.6	7.5	0.3	6.5	2.2	3.6
	11	1.7	1.1	4.3	1.3	0.0	0.0	1.9	0.0
	12	7.5	8.3	3.0	1.1	0.0	0.0	0.0	0.0
Grand River below	13	1.1	1.7	3.2	3.8	4.8	10.2	0.0	0.3
the Confluence with	14	1.4	1.4	3.0	4.6	9.4	18.0	0.8	2.2
the Speed River	15	0.0	0.0	2.2	2.4	7.0	11.0	0.0	0.6
	16	0.0	0.0	0.0	1.3	0.8	4.8	0.0	0.0
	17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

* With Urban Runoff
** Without Urban Runoff

(Figures 20 and 21) were minor and averaged from 0.5 to 1.0 mg/L. The two critical reaches on the Speed River, Reaches No. 7 and 8, were still in violation for 28.1% to 55.9% of the time during the entire simulation period.

The main Grand displayed opposite trends in comparison with the Speed River. The critical reaches, Reach No. 5 (below Kitchener) and Reaches No. 13 - 16, displayed evidence of a decrease in the percent of time in DO violations with the inclusion of urban input. The greatest changes occurred in Reaches No. 5 and 13 where the number of violations reduced by one half during August and September, 1976. Nevertheless, the changes in the daily minimum DO concentrations averaged less than 1 mg/L (Figure 22).

The improvement of the in-stream DO regime of the Speed River with the removal of the urban input is probably due to the reduction of total oxygen demanding load. This reduction has a positive effect due to the limited assimilative capacity of this river.

The simulated response of the main Grand to the removal of urban input is hard to explain. It suggests that the urban input is having a positive effect on this section of the river under present conditions. A possible explanation of this phenomenon is that biomass growth in the main Grand is light limited and the rate of growth is affected by the available light. By reducing the amount of suspended solids in the urban runoff (second run), the turbidity of the river was reduced and more light was allowed to penetrate to plant depth, thus resulting in more biomass growth and lower DO concentrations. It should be noted, however, that the difference between the two runs in terms of the minimum DO concentrations is minor.

The impacts of future loadings of urban runoff on the Grand River were also evaluated. An extreme scenario based on high population projections and land use distributions for the year 2031 was investigated. Pollutant loads for this scenario were generated using the STORM model and input to the GRSM model. The impacts were assessed for high, average and low stream flow conditions.

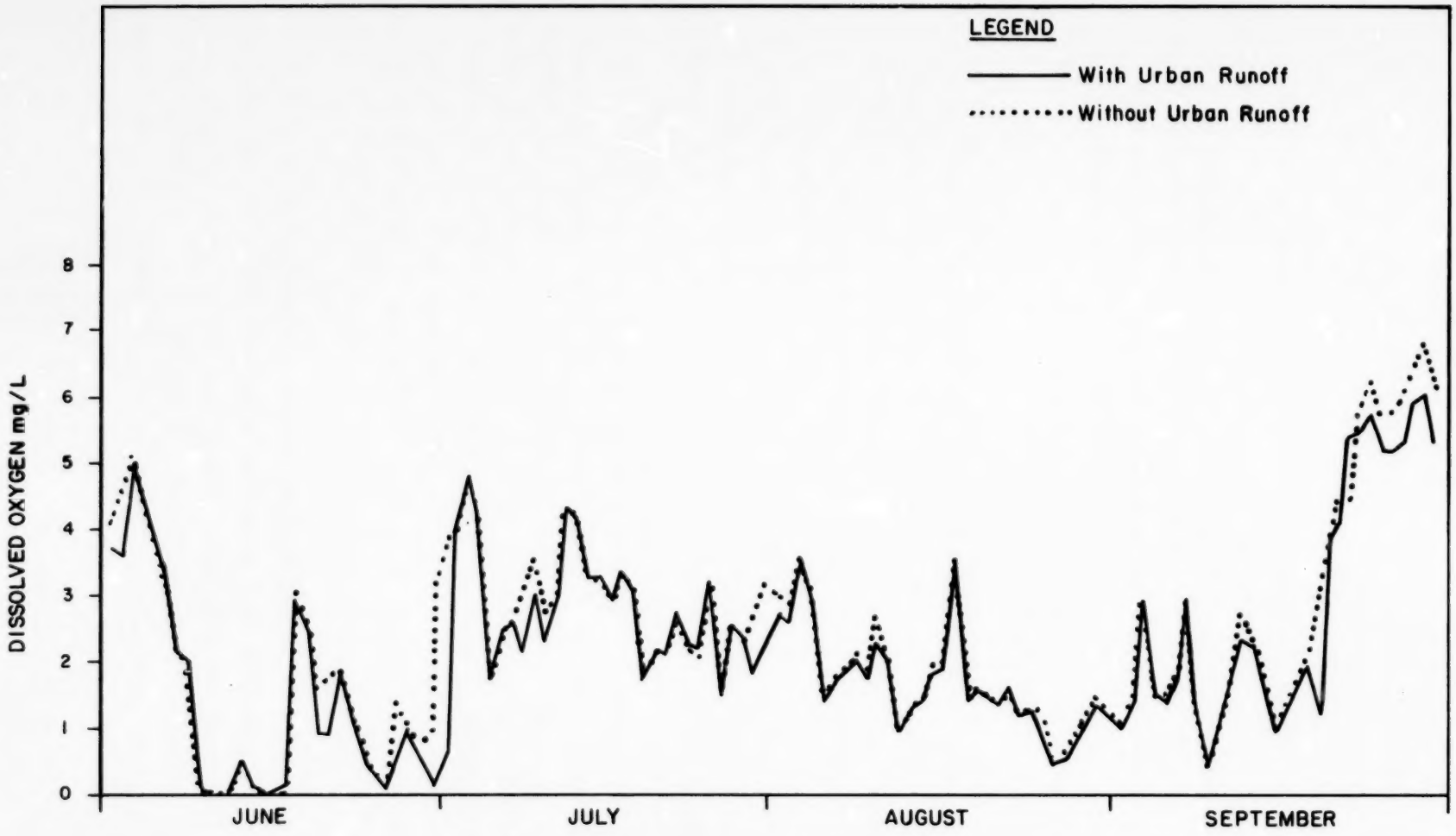

Figure 20 : The Impact of Urban Runoff on Simulated Daily Minimum Dissolved Oxygen Concentrations For Reach No. 8 at Glen Christie Below Guelph on the Speed River

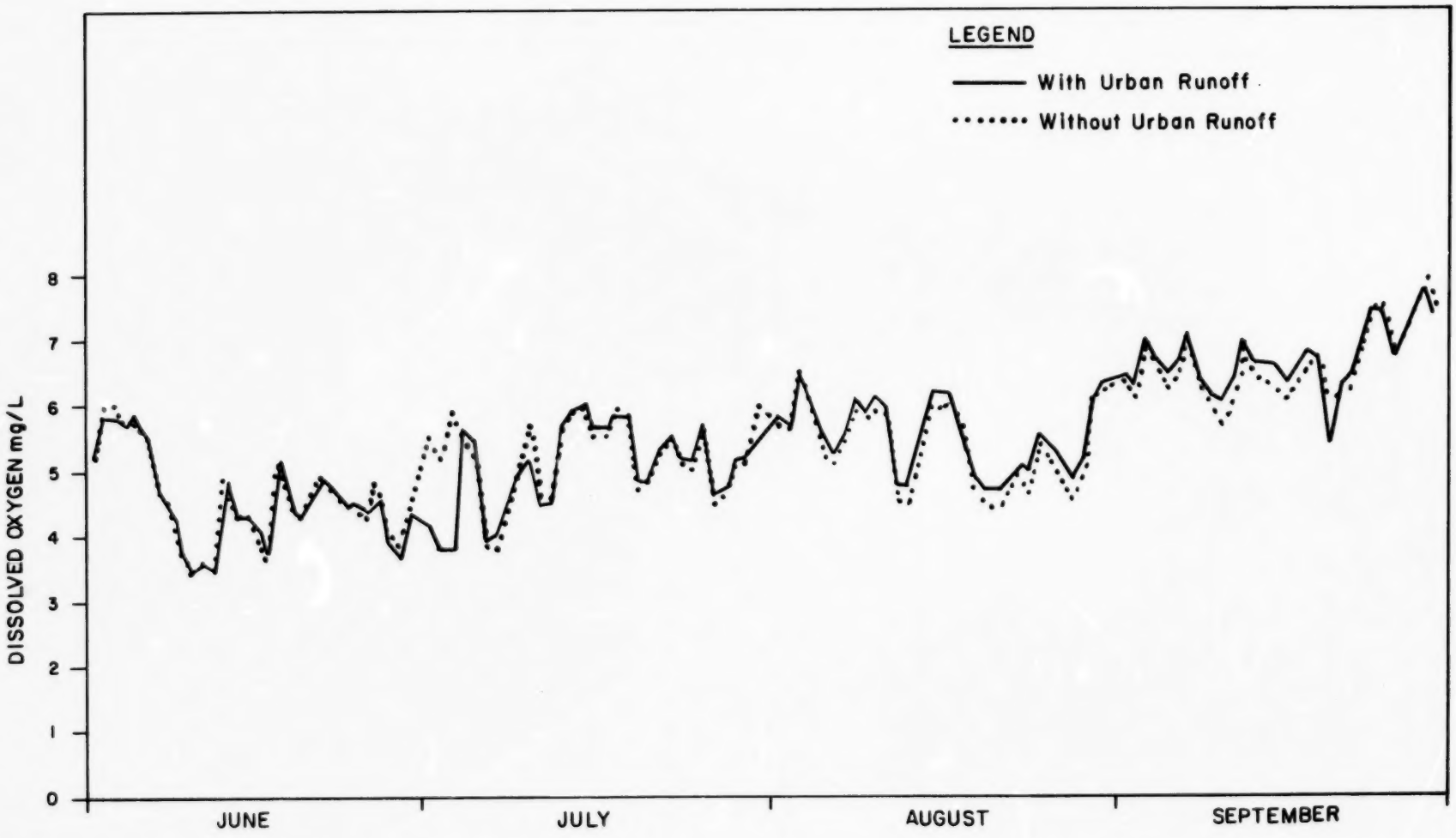

Figure 21 : The Impact of Urban Runoff on Simulated Daily Minimum Dissolved Oxygen Concentrations For Reach No. 12 at Preston on the Speed River

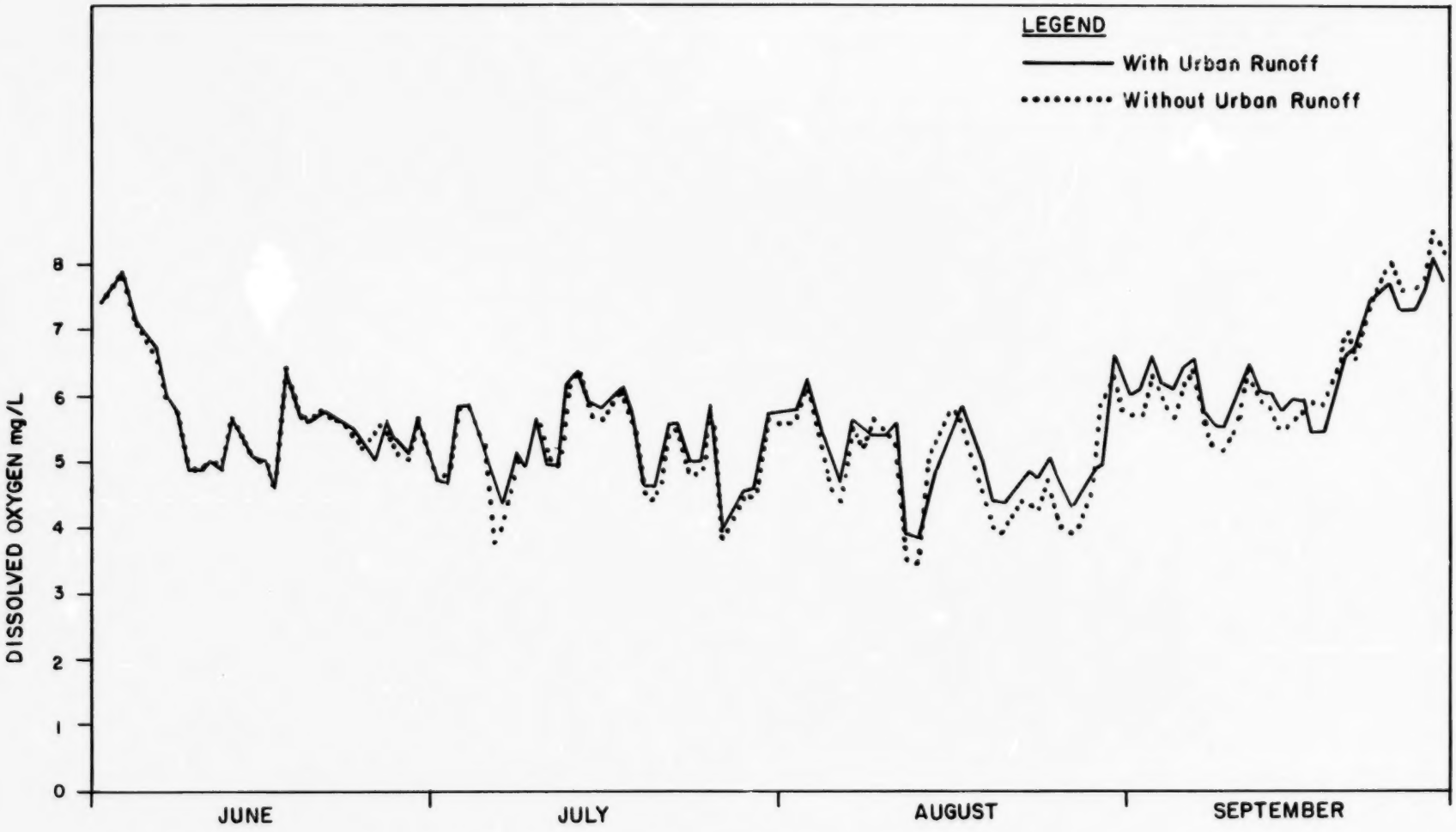

Figure 22 : The Impact of Urban Runoff on Simulated Daily Minimum Dissolved Oxygen Concentrations For Reach No. 16 at Glen Morris Below Galt STP on the Main Grand River

For the Speed River, the percent of time in DO violations under high flow conditions (Table 11) increased by a few percentage points when urban runoff was included. However, for the average and low flow conditions (Table 12 and 13), the effects of including urban runoff could be positive or negative, depending on the individual reach and time.

For the Grand River above the confluence with the Speed River, the effect of urban runoff was relatively small. At the critical reach downstream of Kitchener (Reach No. 5), the percent of time in DO violations under all three flow conditions increased by less than six percentage points when urban runoff was included.

For the Grand River below the confluence with the Speed River, the percent of time in DO violations decreased with the inclusion of urban runoff under both low and average flow conditions (Table 12 and 13). The impacts were not uniform but relatively small under high flow conditions (Table 11).

A comparison of Tables 10 and 12 shows the impact of intensive urban development on the Grand River and Speed River under average flow conditions. For the Speed River (Reaches 6 to 12), the percent of time in DO violations for the 2031 high population projection (Table 12) were lower than those under present conditions (Table 10). The result can be attributed partly to the increased volume of urban runoff which increases the dilution ratio and thus reduces the impact of the total oxygen demand load from the Guelph sewage treatment plant. It can also be attributed to an increase in assimilative capacity, due to higher reaeration rates, resulting from increased flows to the Speed River from the City of Guelph.

The main Grand River (Reaches 1 to 5 and 13 to 21) displayed opposite trends in comparison with the Speed River. The projected percent of time in DO violations for the 2031 high population projections (Table 12) are higher than those under present conditions (Table 10). These trends are mainly due to the increased load of total oxygen demanding wastes from the sewage treatment plants in Kitchener, Waterloo and Cambridge. Intensive urban

Table 11. Results of Two Simulation Runs (With and Without Urban Runoff) in Terms of Percent Time in DO Violations for the 2031 High Population Projection and under High Flow Conditions

LOCATION	REACH	June		July		August	
		Run No. 1*	Run No. 2**	Run No. 1	Run No. 2	Run No. 1	Run No. 2
Grand River between	1	0.0	0.0	0.0	0.0	0.0	0.0
Bridgeport and the	2	0.0	0.0	0.0	0.0	0.0	0.0
Confluence with	3	0.3	0.3	0.0	0.0	0.3	1.3
Speed River	4	5.0	4.2	0.3	0.3	0.5	0.8
	5	27.2	21.7	2.7	3.2	18.3	14.2
Speed River below	6	0.0	0.0	0.0	0.0	0.0	0.0
the Confluence with	7	0.8	0.8	0.0	0.0	0.0	0.0
the Eramosa River	8	9.4	8.1	0.0	0.0	9.7	10.2
	9	0.8	0.0	0.0	0.0	0.0	0.0
	10	18.6	13.9	0.0	0.0	0.8	0.0
	11	9.4	3.6	0.0	0.0	0.5	0.0
	12	11.9	5.3	0.0	0.0	0.5	0.0
Grand River below	13	6.7	5.8	0.0	0.3	2.7	6.7
the Confluence with	14	0.8	0.6	0.0	0.0	0.0	0.0
the Speed River	15	0.0	0.3	0.3	1.3	7.3	11.0
	16	1.4	0.0	0.0	1.1	0.0	0.3
	17	1.4	0.0	0.0	0.0	0.0	0.0
	18	0.0	0.0	0.0	0.0	0.0	0.0
	19	0.0	0.0	0.0	0.0	0.0	0.0
	20	0.0	0.0	0.0	0.0	0.0	0.0
	21	1.1	0.0	0.8	0.0	0.0	0.0

* With Urban Runoff
** Without Urban Runoff

Table 12. Results of Two Simulation Runs (With and Without Urban Runoff) in Terms of Percent Time in DO Violations for the 2031 High Population Projection and under Average Flow Conditions

LOCATION	REACH	June		July		August	
		Run No. 1*	Run No. 2**	Run No. 1	Run No. 2	Run No. 1	Run No. 2
Grand River between Bridgeport and the Confluence with Speed River	1	0.0	0.0	0.0	0.0	0.0	0.0
	2	0.0	0.0	0.0	0.0	0.0	0.0
	3	2.2	2.2	0.0	0.0	0.0	0.0
	4	3.1	3.1	6.2	6.2	3.2	4.6
	5	10.8	9.4	48.7	46.0	53.2	.2
Speed River below the Confluence with the Eramosa River	6	0.0	0.0	0.3	0.0	0.0	0.0
	7	0.6	0.8	3.8	3.8	19.9	27.4
	8	8.1	8.9	3.2	4.6	26.3	29.8
	9	0.6	0.0	0.0	0.0	0.0	0.0
	10	6.7	5.0	0.8	1.9	2.2	0.8
	11	1.9	0.8	0.0	0.0	1.6	0.0
	12	1.7	1.1	0.0	0.0	0.5	0.0
Grand River below the Confluence with the Speed River	13	1.7	2.2	23.4	27.7	41.7	42.7
	14	0.6	1.1	13.2	21.2	43.3	44.9
	15	0.3	0.6	5.1	8.3	23.4	35.5
	16	0.3	0.6	12.6	19.1	36.6	42.2
	17	0.0	0.0	0.0	0.0	0.0	0.0
	18	0.0	0.0	0.0	0.0	0.0	0.0
	19	0.0	0.0	0.0	0.0	0.0	0.0
	20	0.0	0.0	0.0	0.0	0.0	0.0
	21	0.0	0.0	0.0	0.0	0.8	0.0

* With Urban Runoff
** Without Urban Runoff

Table 13. Results of Two Simulation Runs (With and Without Urban Runoff) in Terms of Percent Time on DO Violations for the 2031 High Population Projection and under Low Flow Conditions

LOCATION	REACH	June		July		August	
		Run No. 1*	Run No. 2**	Run No. 1	Run No. 2	Run No. 1	Run No. 2
Grand River between Bridgeport and the Confluence with Speed River	1	1.1	1.1	5.6	8.3	3.5	8.1
	2	0.0	0.0	4.6	4.8	2.2	3.5
	3	4.7	3.9	4.0	7.0	5.1	12.4
	4	13.1	11.7	30.4	29.8	29.8	39.0
	5	33.3	30.0	60.2	54.3	61.3	62.1
Speed River below the Confluence with the Eramosa River	6	0.0	0.0	1.3	0.0	0.3	0.0
	7	8.9	10.3	19.1	18.5	36.0	38.7
	8	22.8	21.7	16.7	15.1	34.1	38.7
	9	1.7	0.0	4.0	0.0	2.2	0.5
	10	20.6	15.6	10.8	15.6	14.2	35.8
	11	10.0	5.3	6.2	0.5	3.0	5.1
	12	11.4	5.8	5.4	0.3	2.2	6.5
Grand River below the Confluence with the Speed River	13	17.8	13.6	43.8	44.1	55.6	58.3
	14	3.9	5.6	26.1	34.1	47.6	54.3
	15	1.4	2.5	19.1	25.8	26.3	45.7
	16	1.4	1.1	25.0	28.2	37.1	55.1
	17	0.0	0.0	3.2	0.0	0.0	0.0
	18	0.0	0.0	0.3	0.0	0.0	0.0
	19	0.0	0.0	0.0	0.0	0.0	0.0
	20	0.0	0.0	0.0	0.0	0.0	0.0
	21	0.6	0.0	4.0	0.0	0.0	0.0

* With Urban Runoff
** Without Urban Runoff

development in the three cities would also result in increased volumes of urban runoff and sewage treatment plant effluent. These increases, however, are small compared with the base flow of the Grand River.

7. CONCLUSIONS AND RECOMMENDATIONS

The characteristics of urban runoff and the magnitude of the associated pollutant loads from the cities of Brantford, Cambridge, Guelph, Kitchener and Waterloo are similar to those reported for other cities in Ontario.

The impact of urban runoff from the five cities on the dissolved oxygen regime in the Grand River is minor under present and high future population projection. Parts of the Speed River below Guelph and certain reaches on the main Grand between Kitchener and Brantford suffer from profuse algae and plant growth during the summer and early fall period. This results in extremely low dissolved oxygen concentrations during the night due to the respiration process. High dissolved oxygen levels are observed during the day as a result of the photosynthesis process. Respiration and photosynthesis are the two dominant in-stream processes in this section of the Grand River system. Improvement of the dissolved oxygen regime would require the control of oxygen demanding materials and nutrient input (mainly phosphorus) from point and non-point sources. These nutrient inputs from urban runoff are small relative to agricultural diffuse sources and sewage treatment plants. Therefore, priority for pollution control measures should be given to those two sources.

The impact of urban runoff on local urban streams is significant. A reduction of pollutants in these streams can be accomplished by various modern storm water management practices. Some preventive methods of reducing pollutants from existing areas are:

a) the location and eradication of all illegal connections of sanitary and industrial waste effluents to storm sewers through surveillance and remedial measures;

b) the reduction of atmospheric emissions which subsequently accumulate on surfaces and are washed off during rain storm or melt events (eg. more use of non-leaded gasoline);

c) the reduction of the use of sodium chloride as a deicing agent on highways to lower chloride loads from urban areas;

d) the initiation of public education programs designed to reduce the accumulation of litter and animal wastes on streets, and to promote the proper use of pesticides and fertilizers on urban land would be helpful in reducing the pollution from phosphorus, bacteria, and pesticides; and

e) the implementation of "best management practices" such as improved street sweeping practices to remove accumulated contaminants from streets, and more frequent catch basin sump cleaning.

In newly urbanizing areas, sediment and erosion control programs should be carried out during the construction phase of development using such techniques as mulching and sodding exposed surfaces, especially drainage channels and sedimentation ponds. Since a significant proportion of the pollutant load of metals and phosphorus is attached to sediment, any sediment control program will reduce the loads of these pollutants as well. Special efforts should be made to control possible chemical and petroleum spills likely from commercial and industrial areas, by providing oil separators and detention ponds.

Detailed surveys and analyses will be required to determine the most cost effective method of improving or protecting the water quality of the small urban tributaries.

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